Report

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ASSESSMENT OF NEW TECHNOLOGIES
FOR NATURAL GAS CONVERSION
USING SCENARIO ANALYSIS

VOLUME I

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EXECUTIVE SUMMARY

This study provides an overall framework for the assessment of research projects in the area of natural gas conversion. The framework was developed to identify opportunities, constraints and critical factors for the conversion of natural gas to liquid fuels and fuel components, and to define possible criteria for evaluating various technological options.

The development of the framework was conducted in several steps. First, a data base on Canadian energy supply and demand, and resources was developed. The analysis of the Canadian energy demand and supply for 1967 to 1987 was summarized in three papers: "Major Constraints Associated with the Exploitation of Resources", "Major Constraints Associated with Markets" and "Fuel Substitutability in Different Market Sectors". These papers are presented in Volume II of the report. Second, the historical trends in the Canadian economy, energy demand, regulations and technology developments were analyzed to identify key variables that influence Canadian energy demand and supply patterns. A list of important variables was prepared and a background paper was written on "Opportunities and Constraints for Natural Gas Conversion Technologies in the Energy Field". The information contained in the background papers in Volume 2 and the identified energy demand/supply patterns were used in the development of the scenarios for transportation fuels demand and supply in Canada.

Four scenarios were developed for future Canadian transportation fuels demand. Each of the scenarios was based on a different set of assumptions. The four scenarios are depicted in Figure I. For each scenario, key factors were identified including economic parameters, availability and price of natural gas, efficiency in existing end-use applications, fuel interchangeabilities, environmental concerns, government involvement in the economy, and key structural changes.

The impact of these factors as they relate to various aspects of fuel production and use was then assessed. Aspects considered included supply and disposition of light crude oil, production, demand for and export of natural gas, consumption of light oil in the transportation sector, pricing of natural gas and transportation fuels, potential for alternative fuels, and projected prices for selected petrochemicals.

In addition, a list of opportunities and constraints for the conversion of natural gas to fuels or fuel components was prepared for each scenario. These are depicted in Table I. The projected energy consumption for the transportation sector under the scenarios is shown in Figure II, while the breakdown of demand by supply source in depicted in Figure III.

The central finding of the scenario analysis was that the most important benefits of natural gas conversion research to alternative transportation fuels would be: 1) the development of more environmentally friendly alternative fuels which would permit sustainable growth in the transportation sector; 2) the diversification of the supply of transportation fuels: 3) the imposition of a ceiling on transportation energy cost; and 4) the reduction of the risk involved in development of synthetic fuels, e.g., CNG vs fuels from bitumen.

The specific findings and conclusions of the scenario analysis were:

- GDP growth and world oil price were the major factors determining domestic energy supply and demand in the HOI and HRD scenarios, however, although GDP and world oil price factors were included in the HVE and the NPF scenarios, the environmental factor had an overriding effect on domestic energy disposition.
- Alternative fuels appear in all four scenarios but for different reasons. In the HOI and the HRD scenarios, the market for alternative fuels is limited to the gasoline additive market and , possibly, to small niches like urban transit. The development of gasoline additives would not likely result in the penetration of alterative fuels to other transportation areas. In the HVE and the NPF scenarios, the markets are increased by fleet vehicles and the need for gasoline extenders for household vehicles.
- Using the year 2007 imports and alternative fuels requirements, significant differences exist between the scenarios. These differences are depicted below.:

  HOI scenario: net light oil import $ 5.1 billions
  alternative fuels $ 300 millions

  HRD scenario: net light oil import $1.4 billions
  alternative fuels $400 millions

  HEE scenario: net light oil import $0.5 billions
  alternative fuels $ 830 millions

  NPF scenario: net light oil export $ 6.0 billions
  alternative fuels $ 1.8 billions

- The significant net export of light crude oil under the NPF scenario is due to a combination of two factors: environmental concerns and high world oil prices, where commercialization of non-petroleum fuels and increased energy efficiency result in increased availability of light crude oil for export.

- A key element of natural gas conversion in all of the scenarios is the availability in Canada of a significant additional volume of natural gas from conventional and frontier areas, as the price of natural gas increases. Under the high environmental protection HVE scenario, the price of natural gas increases to a point where it is priced at 120 percent of oil, creating an economic barrier for alternative fuels from natural gas. The relative price increase in natural gas can be counteracted through the use of technological advances that allow decreased exploration and production costs, technological improvements in natural gas conversion, and possible strategic options such as vertical integration of petrochemical industries or remote-site utilization of natural gas.

- Increased energy efficiency and conservation efforts in the transportation sector would benefit the same sector under all the scenarios. Under the low oil price scenarios, these factors would help reduce imports of light crude oil. Under the high oil price scenarios, decreased consumption of premium fuels would lead to an increase in the net export of energy products such as light and heavy crude, natural gas and electricity.

- A significant element in all of the scenarios is the export of natural gas to the United States. It is of interest that the level of export remained relatively constant under all of the scenarios - around 50×10^9 m^3/y.

- Environmental concerns over carbon dioxide will not provide sufficient incentive for production of alternative fuels from natural gas by conventional natural gas conversion technologies. CNG is the main alternative fuel for transportation that actually reduces CO_2 emission. New technologies are required for natural gas conversion if net CO_2 emissions are to be reduced.

- Specific opportunities or market niches were identified in the individual scenarios, for example, natural gas based fuels used for fleet vehicles in the HRD, HVE and NPF scenarios provide means to reduce the cost of transportation fuel and reduce the carbon dioxide emissions by the sector. For truck freight, in the HVE and NPF scenarios, natural gas based fuel would permit the maintenance of growth in this sector while reducing the consumption of petroleum based fuels as mandated by government to reduce carbon dioxide.

- The study has shown that methanol, because of its cost, has the best pricing opportunities in the mid-1990's.

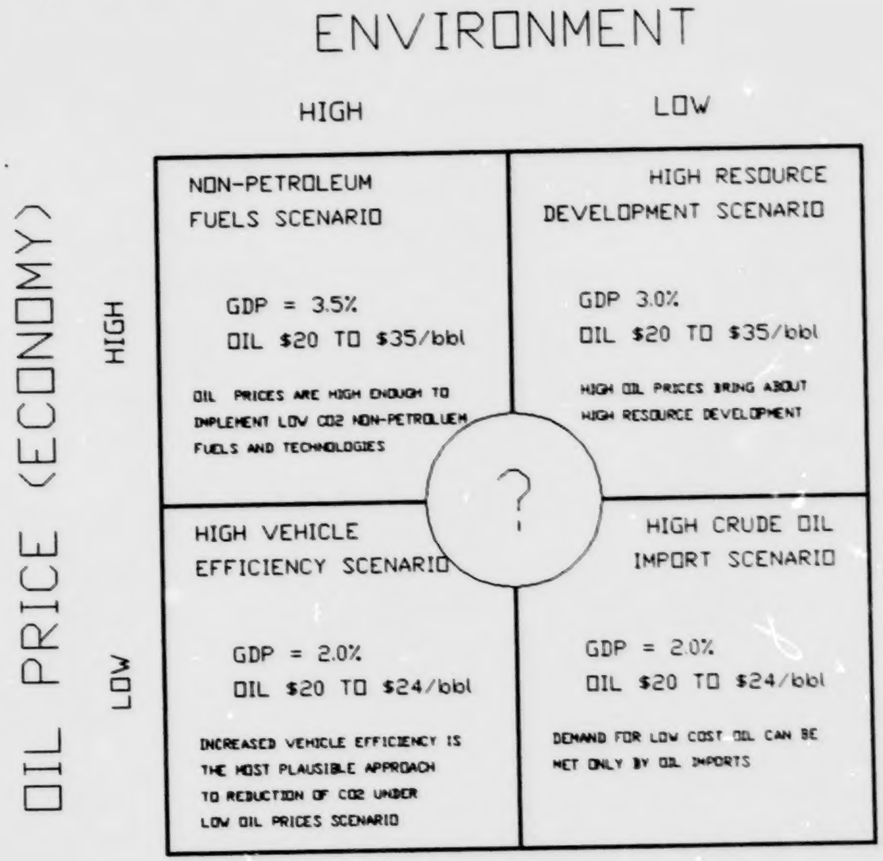
A number of recommendations for future research were presented, including examination of regional differences in Canadian energy supply and disposition. The "broad brush" approach encompassing all of Canada resulted in loss of information on regional opportunities. These opportunities may be quite significant in development of strategic planning for transportation fuels research.

The scenarios developed in this study are referred to as "learning scenarios". Consequently , the effect of dislocations in any of the assumptions, e.g., sudden disruptions in imported light crude oil supplies, were not considered. Possible effects of abrupt increase or decrease in crude oil or natural gas prices and supply, the effect of price oscillation, etc., should be evaluated as part of the continued work in this area. Also of interest, is how the factors of high environmental concern and conservation would affect the petrochemical industry.

Finally, the scenarios developed were based, in general, on an economic view of the energy and transportation market forces such as economic growth and world oil prices combined with a qualitative cost analysis of broad fuel commodities and several environmental factors. This approach has some weaknesses, however, since society's values and goals, and with it government policies, change over long periods like the 20 years considered here. We recommend that a third theme, "Social and Government Policy Constraints", be considered in the analysis of the strategic issues in planning for transportation fuels research.

Table I. SUMMARY OF OPPORTUNITIES AND CONSTRAINTS FOR NATURAL GAS BASED ALTERNATIVE TRANSPORTATION FUELS

SCENARIO	MARKET OPPORTUNITIES	CONSTRAINTS
High Oil Import Scenario	- gasoline enhancers - urban transit buses	- availability of low cost light crude oil
High Resource Development Scenario	- gasoline additives - remote natural gas - urban buses and fleet vehicles	- increased production and modification of petroleum refineries - good returns on natural gas sold to thermal markets
High Vehicle Efficiency Scenario	- gasoline additives - urban transit and fleet vehicles - truck freight	- poor economics of alternative fuels - lack of government initiatives for alternative fuels
Non-Petroleum Fuels Scenario	- gasoline extenders - fleet and urban vehicles and freight - remote natural gas - agricultural fuels	- higher than expected vehicle efficiency improvement - lack of advancement in natural gas conversion technology



OIL PRICE (ECONOMY)	ENVIRONMENT: HIGH	ENVIRONMENT: LOW
HIGH	NON-PETROLEUM FUELS SCENARIO GDP = 3.5% OIL \$20 TO \$35/bbl OIL PRICES ARE HIGH ENOUGH TO IMPLEMENT LOW CO2 NON-PETROLUEM FUELS AND TECHNOLOGIES	HIGH RESOURCE DEVELOPMENT SCENARIO GDP 3.0% OIL \$20 TO \$35/bbl HIGH OIL PRICES BRING ABOUT HIGH RESOURCE DEVELOPMENT
LOW	HIGH VEHICLE EFFICIENCY SCENARIO GDP = 2.0% OIL \$20 TO \$24/bbl INCREASED VEHICLE EFFICIENCY IS THE MOST PLAUSIBLE APPROACH TO REDUCTION OF CO2 UNDER LOW OIL PRICES SCENARIO	HIGH CRUDE OIL IMPORT SCENARIO GDP = 2.0% OIL \$20 TO \$24/bbl DEMAND FOR LOW COST OIL CAN BE MET ONLY BY OIL IMPORTS

Figure I. FOUR SCENARIOS SELECTED

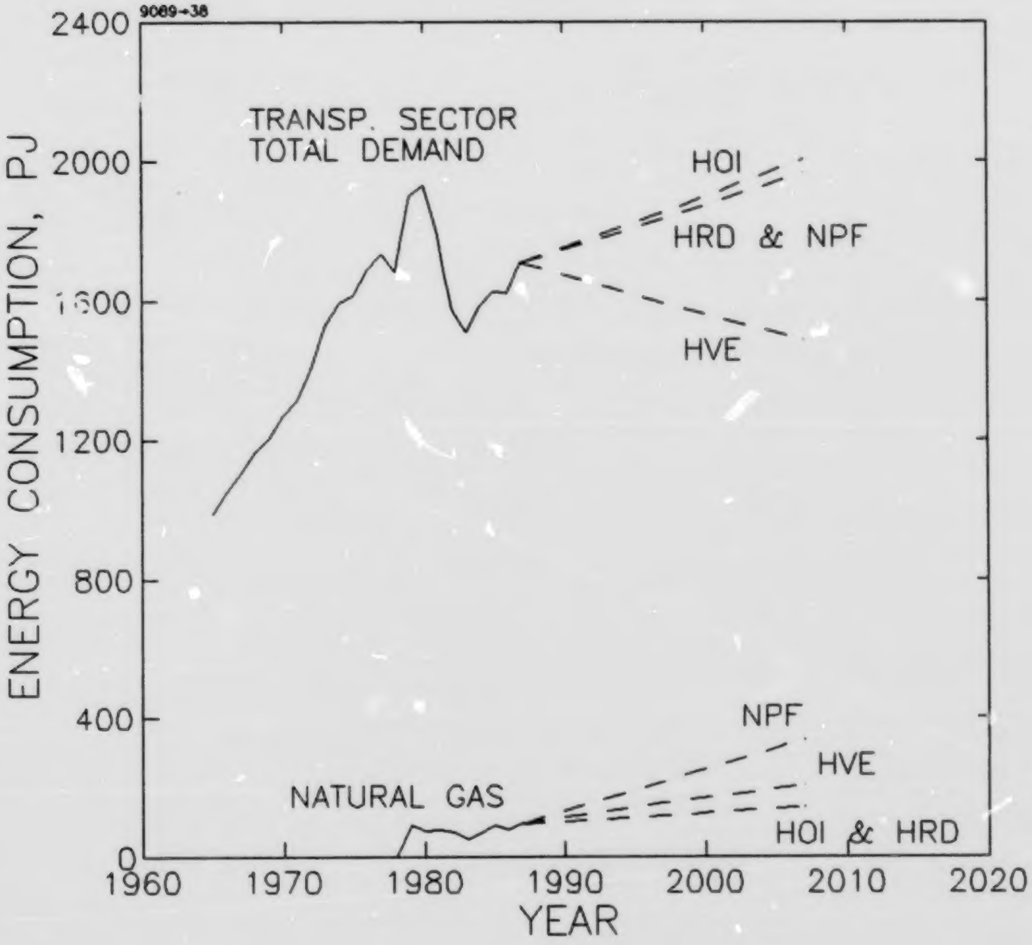


Figure II. **HISTORICAL AND PROJECTED ENERGY CONSUMPTION FOR THE TRANSPORTATION SECTOR**

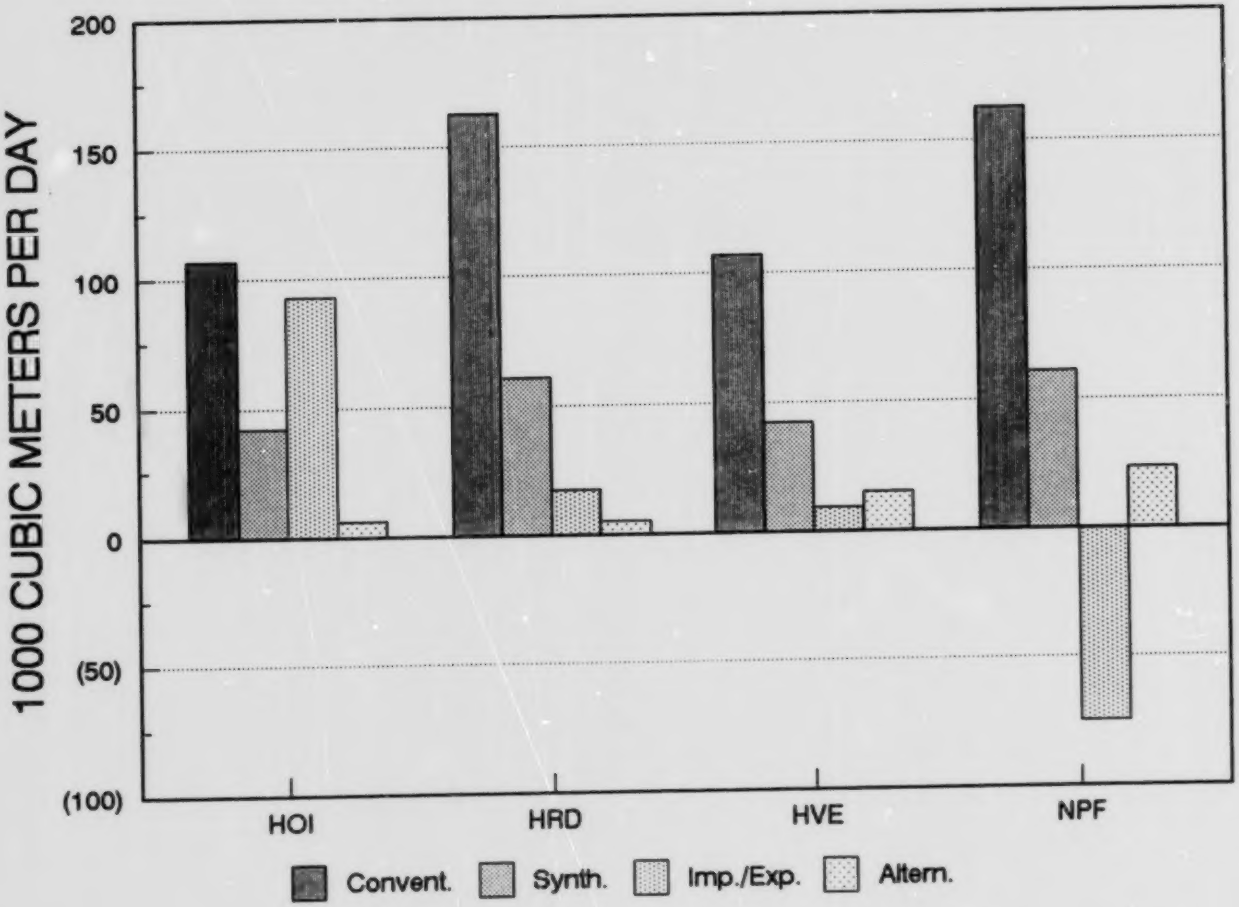


Figure III. CANADIAN LIGHT CRUDE OIL DEMAND AND SUPPLY IN THE YEAR 2007 (Mm^3/d)

Résumé

Cette étude présente un cadre de référence pour l'évaluation des projets de recherche sur la conversion du gaz naturel. Ce cadre définit les opportunités et les contraintes qui existent pour les technologies de conversion du gaz naturel. Des critères servant à l'évaluation des différentes options techniques sont aussi définis.

Le développement du cadre de référence a été fait en plusieurs étapes. Premièrement, une base de donné sur l'offre, la demande et les ressource énergétiques a été développée. L'analyse des donnés pour la période de 1967 à 1987 a permis d'identifier les facteurs clés déterminant l'offre et la demande en énergie au Canada. Une série de trois articles présentés au Volume 2 de ce rapport résume les observations. Ces informations ont été utilisés pour développer des scénarios décrivant les tendances énergétiques futures dans le domaine des transports.

Quatre scénarios ont été développés. Chaque scénario se base sur différentes suppositions. Le premier scénario suppose que nos besoins en carburant de transport sont rencontrés principalement par l'importation de quantités élevées de pétrole. Ce scénario est appelé **High Oil Import (HIO)**. Le deuxième scénario suppose un développement accéléré de nos ressources. Ce scénario est appelé **High Resource Development (HRD)**. Le troisième scénario se base sur une diminution de la demande en énergie créée par un soucis de protéger l'environnement. Ce scénario est appelé **High Vehicle Efficiency (HVE)**. Le dernier scénario examine la possibilité d'une économie basée sur des carburants alternatifs. Ce scénario est appelé **Non-Petroleum Fuels (NPF)**. Pour chaque scénario les facteurs clés comme les paramètres économiques, le prix du gaz naturel, l'efficacité énergétique des différentes applications, le degré d'interchangeabilité des carburants, les facteurs écologiques, l'influence du gouvernement sur l'économie, et les facteurs structurels ont été identifiés. L'impact des facteurs retenus sur la production de carburants a été déterminé tout en tenant compte des ressources disponibles ainsi que de la demande et des prix relatifs des différents types de carburant.

L'analyse des différents scénarios nous a permis de dresser une liste des opportunités et des contraintes pour la production de carburant liquide à partir du gaz naturel.

Les principales conclusions de cette analyse des scénarios sont que la recherche sur la conversion du gaz naturel pourrait: 1) contribuer au développement de carburants de substitution plus propres; 2) permettre une diversification des sources de carburants; 3) imposer un plafond sur le coût des pétroles importés; et 4) réduire les risques associés à l'exploitation des sables bitumineux en fournissant une alternative.

Les scénarios développés dans cette étude sont des scénarios d'apprentissages. Ces scénarios ne considèrent pas de dislocations majeures sur les facteurs utilisés tel par exemple un problème d'approvisionnement des pétroles importés. L'effet de changements majeures devrait être évalué lors d'une étude subséquente. Il serait aussi intéressant d'examiner comment une augmentation de la protection de l'environnement affecterait l'industrie pétrochimique.

Finalement, les scénarios sont basés sur des notions de macro-économie i.e. ce sont les forces du marché tel que la croissance économique, l'offre et la demande, qui influencent le marché des commodités énergétiques. Cette approche a certaines faiblesses puisqu'a long terme, les valeurs et les objectifs de la société, ainsi que les politiques du gouvernement changent. Il est recommandé de faire une étude supplémentaire sur le thème "Contraintes sociales et politiques gouvernementales" afin d'analyser les thèmes stratégiques concernant la recherche dans le domaine des carburants de transport.

Tableau 1 Résumé des opportunités et des contraintes concernant la production de carburants alternatifs à partir du gaz naturel.

Scénario	Opportunités	Contraintes
HIO	- Système de transport en commun (autobus) - Produit à haut octane	- disponibilité de pétrole léger à un prix abordable
HRD	- additif pour gazoline - exploitation du gaz dans les régions éloignées - autobus et autres	- capacité de production et de raffinage des pétroles lourds - bonne profitabilité pour le gaz vendu sur les marchés conventionnels
HVE	- additif pour gazoline - exploitation du gaz dans les régions éloignées - autobus et autres	- non-compétitivité des carburants alternatifs - manque d'initiative des gouvernements pour promouvoir les carburants alternatifs
NPF	- Produit à haut octane - exploitation du gaz dans les régions éloignées - autobus et autres	- amélioration exceptionnelle de l'efficacité des véhicules automobiles - manque d'avancement dans le domaine des technologies de conversion du gaz naturel

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1.0. INTRODUCTION

The objective of this project is to provide a comprehensive reference document to assist CANMET with the establishment of a framework for its research and development program on the direct conversion of natural gas to liquid fuels or fuel components.

CANMET has the responsibility for coordinating and implementing a national research program on the conversion of natural gas. The major challenge regarding the coordination of this program is to choose relevant objectives leading to the development of useful technologies. Due to the long lead-time required for the development of conversion technologies, the identification of future needs is difficult. The availability of an explicit set of selection criteria and the identification of key variables are necessary conditions for successful strategic planning and project evaluation activities.

The purpose of this study is to provide an overall framework for the assessment of research projects on natural gas conversion technologies. The framework can be used to identify opportunities, constraints and critical factors for the conversion of natural gas to liquid fuels and chemicals, and to define possible criteria for evaluating various technological options.

The work for this study was conducted in three stages.

The first stage was the development of a data base. The availability of a credible information base is a key feature for a viable strategic planning system. The data base will provide a comprehensive reference document in support of the assessment framework.

The data base was developed for the Canadian energy situation with respect to supply information and demand, or market, information. Three separate background papers, contained in Volume II of this Report, resulted from this stage of the work.

The first paper entitled "Major Constraints Associated with the Exploitation of the Resources" contains information on the size and location of Canada's known reserves of natural gas, conventional oil, frontier oil, heavy oil/bitumen, coal and electricity. This paper identifies the rate of growth in Canada's energy reserves over the last twenty years. The major constraints associated with the exploitation of these reserves are identified. The factors considered include technological, environmental, political and social/economic factors.

The second paper entitled "Major Constraints Associated with Markets" describes the demand patterns over the last twenty years in Canada for transportation fuels, heating oil, electricity, coal, petrochemical feedstock and natural gas. The paper also identifies major constraints associated with each of the markets. The factors considered include technological, environmental, political and social/economic factors.

A third paper resulted from the assessment of the Canadian energy supply and demand information. The issue of fuel substitutability is important since it determines the flexibility associated with a given resource and the degree of competition that can exist between alternate energy sources in the marketplace. Thus a separate background study paper was prepared entitled "Fuel Substitutability in Different Market Sectors".

The second stage of the study consisted of an analysis of the data base to determine historic trends in the Canadian economy and to identify key variables that influence the supply and demand of energy products in Canada. The first task in the second stage was to prepare a comprehensive list of relevant variables or issues that affect the Canadian energy supply and demand situation. The list of variables was then used to identify key factors which define the Canadian energy situation.

The background study paper which resulted from the second stage work is entitled "Opportunities and Constraints for Natural Gas Conversion Technologies in the Energy Field". It assesses the energy scenario for Canada and it discusses the historic relationships between the key factors identified for the Canadian situation. This paper is contained in Volume II of the Report.

The third stage in the development of the assessment framework was the use of scenario analysis to project several possible future situations for Canadian energy supply and demand. The role of the scenario analysis stage was to provide a description of the relationships between the key factors identified for the Canadian situation. This stage consisted of building a model of the Canadian energy situation based on a different set of assumptions for each of four scenarios. The scenarios that were chosen cover combinations of high and low economic growth and high and low environmental concern variables.

The output of the third stage of the project is contained in Section 4 of Volume I of this Report. The results of the scenario analysis technique are summarized and the impact on methane conversion research and development assessed.

The final stage of work, which is beyond the scope for this project, will be the development of research strategies by CANMET.

The analysis conducted in this Report is the first step, or the learning step, in a scenario analysis process. Before the overall assessment framework can be focused on specific natural gas conversion technologies, a second set of planning scenarios should be undertaken to refine the assessment framework. However, CANMET can use the framework provided in this Report to review in a broader perspective the merits of its existing assessment criteria and the direction of its research program on the direct conversion of natural gas to liquid fuels and fuel components.

2.0. FRAMEWORK DEVELOPMENT FOR NATURAL GAS CONVERSION R&D PLANNING

2.1. Methodology Used

As stated in the Introduction, the purpose of this study is to provide an overall framework for the assessment of research projects in the area of natural gas conversion. The basic technique that has been used to develop the framework in this study is called scenario analysis.

In their book, The Year 2000, Kahn and Wiener define scenarios as; "hypothetical sequences of events constructed for the purposes of focusing attention on causal processes and decision points."

Scenario analysis is therefore an approach to thinking about and assessing the future. It focuses on the factors and variables that, in combination, will determine the outcome for a given situation. Forecasts, on the other hand, give an extrapolation of present trends. With forecasts, the focus is on the results of the analysis rather than on a description of the mechanisms that are perceived as having the greatest effect in determining the results.

This does not mean that scenario analysis dispenses with any quantitative description of the future that it is assessing. Indeed, in this Report, where future scenarios are described, the description is primarily qualitative but quantitative data is also presented for illustrative purposes. However, the qualitative data are not represented as hard numbers. Rather, the qualitative data provides a means of assessing the outcome of the different scenarios presented in a relative way.

Scenario analysis also allows the incorporation of information that cannot easily be quantified into the judgement process. For example, political, legal and technological factors can be qualitatively assessed and described as part of the scenario and the impact of the factors taken into account in the quantitative results.

The purpose of this study was not to provide a review of all of today's current forecasts for future energy prices. Rather, the exercise was to learn how to use scenario analysis for the assessment of research projects in natural gas conversion.

Instead of trying to focus on a single most probable energy future for Canada, the study attempts to plan against several energy futures for Canada. Thus, if certain natural gas conversion technologies are applicable given the outcome of all of the scenarios evaluated, then those conversion technologies could be judged to be better candidates for a research strategy than those that only fit certain scenarios.

Because the scenarios in this study focus on the underlying variables and factors that shape Canada's energy future, to be comparable, each scenario has to address the same set of variables, and how they interact. In addition, each scenario has to be consistent within itself.

The idea was not to get each scenario right, because there is no right scenario. Rather, emphasis was placed on ensuring that each scenario was plausible given the assumptions made to define the scenario. It was expected that by examining the interaction of the underlying variables within each scenario, certain conclusions about Canada's energy future might become evident that otherwise may not have been recognized.

Energy supply, demand and price relationships were an important aspect of the review but not the key. Rather, the scenario analysis technique was used to develop an understanding of the trends and relationships between the supply and demand factors in the marketplace. A better understanding of the energy markets will allow for better decisions on research strategies.

The first step in performing the scenario analysis was the compilation of a data base on Canada's energy resources. The data base encompasses current oil, gas, and coal reserves, electrical generating capacity, past and present production, and the rate of reserve additions. The data base was compiled in a spreadsheet format and macros developed to manipulate the data into tables and graphs.

Concurrent with the development of the data base on energy resources, a data base was prepared on Canadian energy markets. This data base took into account amounts of energy consumed by the various sectors within the Canadian economy on a current and a historic basis as well as pricing in certain circumstances. Again this data base was compiled into a spreadsheet format and macros developed to manipulate the data.

After the data bases were complete, an analysis of the data was performed to identify trends and variables affecting Canadian energy supply and demand. Three major background study papers were prepared at this stage addressing the constraints associated with Canada's energy supplies, Canada's energy markets and fuel interchangeabilities in the Canadian marketplace. The constraints were addressed under the headings of technological, environmental, economic, regulatory or of a government nature. These background papers are contained in Volume 2 of this Report.

The next stage in the process entailed the development of a complete list of all the possible variables that could have an effect on the Canadian energy situation. A fairly extensive review of literature was necessary and all variables were listed, whether or not they were initially thought to be of a peripheral nature. The complete list of these variables is contained in Appendix A to Volume 1 of this Report.

The list of variables was then reviewed and grouped under seven headings. Part of this process was a crude ranking of the variables according to the perceived importance of each variable to a scenario analysis for natural gas conversion processes.

Once the list of variables had been narrowed to the seven major headings, they were considered to be the key factors determining natural gas use in Canada for the purposes of the study. A fourth major background study paper was then prepared addressing the opportunities and constraints for natural gas conversion technologies in the Canadian energy field.

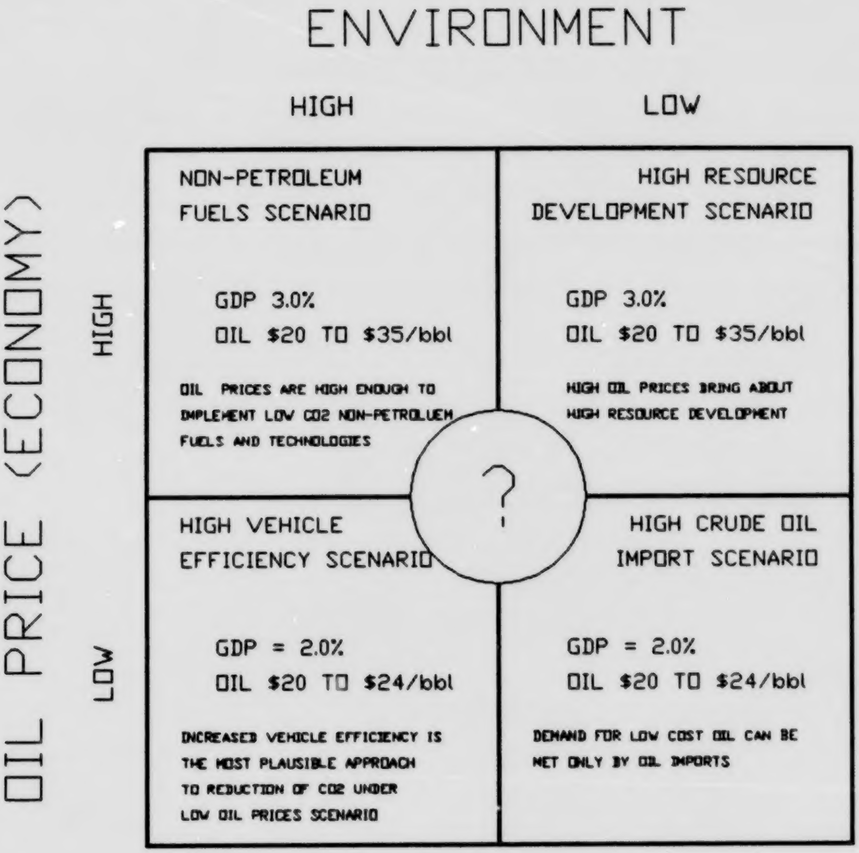
It is important to note the amount of time devoted on this project to developing the data base and to identifying the underlying factors that have shaped Canada's energy situation on a historic basis. Fully 50 percent of the time spent on the study was devoted to the development and assessment of the background information including identification of opportunities and constraints for natural gas conversion technologies.

After completion of the background work on the Canadian energy scene it was time to select themes for the scenario analysis. The themes were to be related to one or more of the key factors and they were to be sufficiently different to allow for a good understanding of how the factors would interact given the different assumptions.

Two factors were selected which were judged to be the most relevant based on the work performed to that point in time. The factors that were selected were economic growth and environmental concern. To assess how the remaining factors interacted with the chosen factors, themes were developed based on assigned "values" for these factors. High and low "values" were assigned to each of these factors with the economic growth factor being defined in quantitative terms - i.e., GDP and world oil prices, while the environmental values were qualitative in nature.

By combining the themes, four possible scenarios were developed: a High Oil Import scenario (low economic growth/low world oil prices coupled with low environmental concern); a High Resource Development scenario (high economic growth/high world oil prices coupled with low environmental concern); a High Vehicle Efficiency scenario (low economic growth/low world oil prices coupled with high environmental concern); and, a Non-Petroleum Fuels scenario (high economic growth/high world oil prices coupled with high environmental concern). A representation of these scenarios is depicted in Figure 1.

Narratives were then written on each scenario addressing the key factors in a similar fashion. Quantitative data was projected for each scenario by using product pricing and demand equations. The time frame that was assessed for each scenario was twenty years with quantitative data being presented at ten and twenty year intervals.



OIL PRICE (ECONOMY)	ENVIRONMENT: HIGH	ENVIRONMENT: LOW
HIGH	NON-PETROLEUM FUELS SCENARIO GDP 3.0% OIL \$20 TO \$35/bbl OIL PRICES ARE HIGH ENOUGH TO IMPLEMENT LOW CO2 NON-PETROLEUM FUELS AND TECHNOLOGIES	HIGH RESOURCE DEVELOPMENT SCENARIO GDP 3.0% OIL \$20 TO \$35/bbl HIGH OIL PRICES BRING ABOUT HIGH RESOURCE DEVELOPMENT
LOW	HIGH VEHICLE EFFICIENCY SCENARIO GDP = 2.0% OIL \$20 TO \$24/bbl INCREASED VEHICLE EFFICIENCY IS THE MOST PLAUSIBLE APPROACH TO REDUCTION OF CO2 UNDER LOW OIL PRICES SCENARIO	HIGH CRUDE OIL IMPORT SCENARIO GDP = 2.0% OIL \$20 TO \$24/bbl DEMAND FOR LOW COST OIL CAN BE MET ONLY BY OIL IMPORTS

Figure 1. FOUR SCENARIOS SELECTED

As a final stage in the study process, the results of the four scenarios were reviewed and compared. An assessment was then prepared of future markets for natural gas conversion products, the alternative energy sources for these markets, and the possible impact of the study on natural gas conversion research and development in Canada.

It should be noted that for an initial scenario analysis study, the level of quantification and detail could not be overdone particularly when dealing with multiple scenarios. If the narratives become too unwieldy, it is difficult for anyone not directly involved in the preparation of the scenarios to assimilate the information. Because the importance of the scenario analysis technique is the development of an understanding of how the factors that define the Canadian energy situation interact, it is not appropriate to discourage people from reading the analysis because of its sheer bulk. For the same reasoning, it is not appropriate to summarize and present a final set of numbers as the findings of the scenario analyses that have been performed.

It should be emphasized that the scenarios that have been developed in this Report are a first pass exercise. The project has been a learning exercise on the scenario analysis technique with limited time and resources allocated to it.

However, this is a normal approach to scenario analysis. The first set of scenarios are called learning scenarios. Learning scenarios typically quantify the alternate outcomes of some of the more obvious uncertainties. A second attempt at scenario planning can refine the technique for natural gas conversion assessment and focus in on more detail or different areas. The second stage of scenario analysis is called the planning or decision scenario stage.

Involvement of more people in the process is also necessary in the second stage. This should include the involvement of more expertise in those areas that are key to the evaluation process. Also, the number of scenarios should be kept to the minimum, with most papers reviewed in this area suggesting three to six scenarios as the optimum number.

It can be noted that it took Shell Oil Co. some ten years to develop the technique of decision scenarios. (Wack, 1985)

According to Wack, for Shell Oil, the learning scenarios were good search tools. They were not yet effective planning devices, but without them Shell Oil would have been unable to develop the next generation of scenarios. The real fruits of scenario analysis for Shell Oil were focused scenarios which were custom tailored around a strategic issue or a specific market or investment project.

In summary, the basis for the methodology used in this study is scenario analysis. In this Report, learning scenarios have been prepared for the assessment of natural gas conversion technologies. The learning scenarios are supported by a very comprehensive data base and a series of background study papers which identify and describe the key factors which determine the Canadian energy situation.

2.2. Modelling Fuel Demand and Prices

The description of the methodology used in the scenario analysis (Section 2.1) stresses the qualitative character of the learning scenarios. However, a quantitative measure and description of the relationships between different scenario factors is also necessary. The quantitative description provides for a relative comparison of the energy prices and demands in the various scenarios and thus is an important part of the overall assessment framework for strategic planning purposes.

The quantitative description of the various scenarios have been developed through the use of econometric models. These models describe the impact that various factors have on the market opportunities for natural gas conversion technologies. These models do not forecast energy demand levels or prices, but they do provide a measure of the effects that crude oil prices or GDP can have on the market size and pricing of transportation fuels. The econometric models can thus be used to rank the effects of different factors according to their importance and impact. For example, using a demand/price model we can study the effect that crude oil price and GDP growth have on the demand for crude oil. We can also use the econometric models to answer questions such as: "by how much would crude oil price have to be increased in order to decrease the crude oil consumption by 20 percent?"

The demand/price models provide a semiquantitative measure of the change we should expect in the demand and prices for transportation fuels, as factors such as world oil price and GDP growth vary between the scenarios.

As part of this study we reviewed the econometric methodologies used for forecasting by the NEB, GRI, CERI and AERCB, and we have concluded that the approach used by CERI to forecast oil markets and prices, based on demand equations, would be suitable for the learning scenarios. CERI's approach is relatively simple, semiquantitative, and capable of incorporating, indirectly, a number of factors which influence the price/demand relationships for various fuels.

The general methodology used for calculating total crude demand for all Canadian end-use sectors is depicted in Figure 2. We assumed that the demand for crude oil and refinery products depends on fuel prices, GDP growth and the previous level of demand for the fuel. The total crude demand would be then the aggregated total of the demand for four refinery products (gasoline, middle distillates, heavy fuel oil and other), each governed by its own demand equation given by:

$$D_t = a(\$\ \mathrm{Fuel})^{b}(\mathrm{GDP})^{c}(Dt-1)^{1-d} \qquad (1)$$

where D_t = demand for fuel in year "t"

a = proportionality coefficient

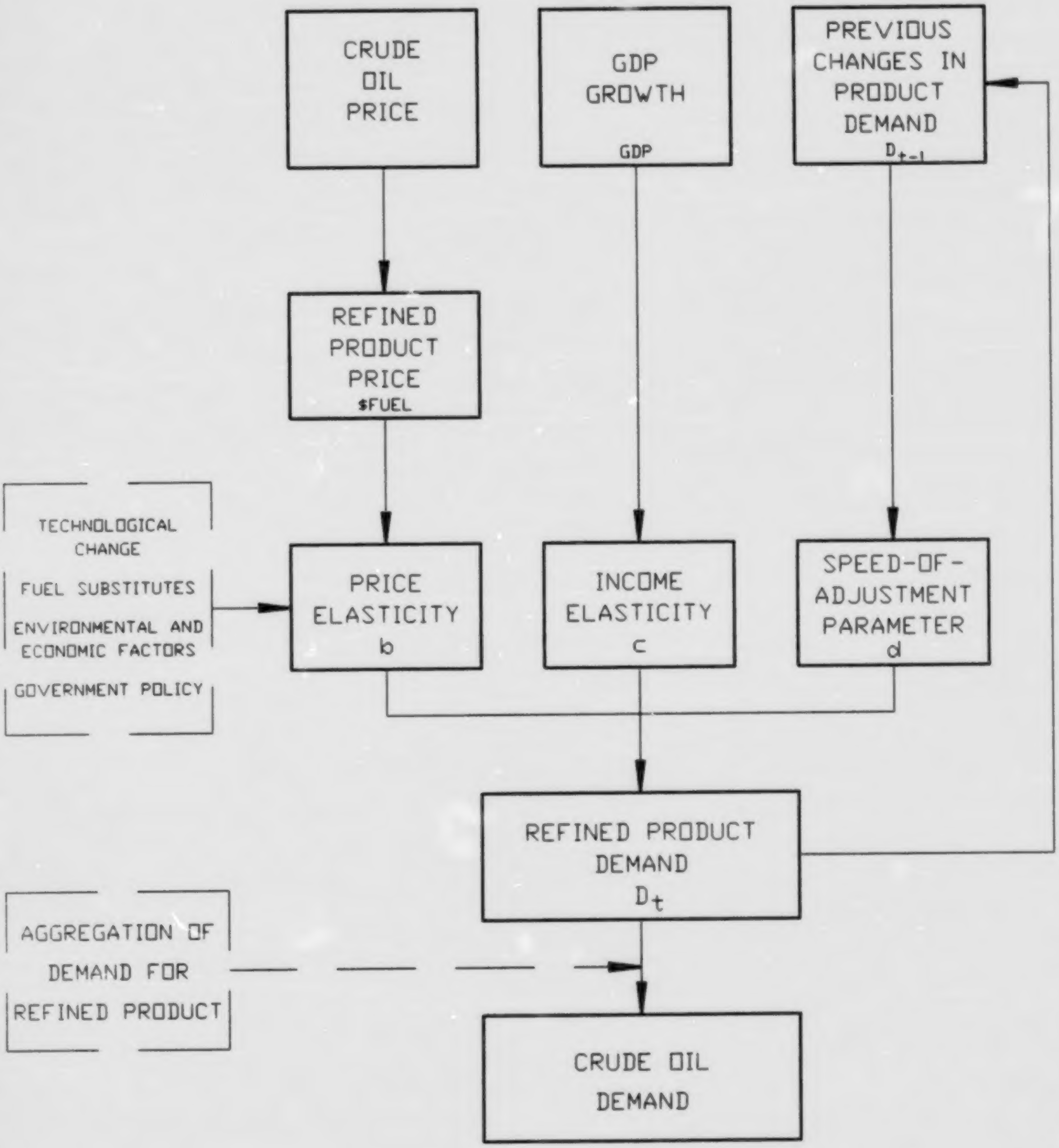


Figure 2. STRUCTURE OF THE DEMAND MODEL

b = price elasticity coefficient
c = income elasticity coefficient
d = speed-of-adjustment coefficient
t = time (year)

The demand model requires that fuel prices be input for each year. These prices are calculated by a set of equations relating fuel prices to crude oil prices (Appendix B). The applied equations were regressed from historical retail price data for gasoline and other refinery products.

Since in each scenario we specify the change in crude oil prices, the growth of gross domestic product and fuel consumption for the year 1987, equation (1) can describe the change in demand for various transportation fuels and crude oil over the analysis period. However, before applying the demand equations to different scenarios, we tested the predictive capabilities of the equations versus the much more sophisticated forecasting models used by the NEB, using the same assumptions about future crude oil prices and GDP growth. Table 1 presents the results of the forecasted and model predicted crude oil demand for all of Canada and the transportation sector. As is apparent, the model calculated crude oil demand is consistent with the demand predicted by the NEB.

Table 1. COMPARISON OF NEB AND CERI FORECASTS VS DEMAND EQUATION MODEL

ASSUMPTIONS		PROJECTED CRUDE OIL DEMAND, PJ			
	OIL PRICE	1995		2000	
GDP % GROWTH	$/bbl 1987-2007	FORECAST	MODEL	FORECAST	MODEL
NEB Transportation Sector					
2.2	20-24	1937	1912	2072	1979
2.9	20-36	1952	1898	2138	1952
NEB Total Canadian					
2.2	20-24	3391	3461	3664	3610
2.9	20-36	3415	3425	3755	3548
CERI Total Canadian					
3.0	18-30	3355	3416	3450	3701

The major advantages of the CERI model are its simplicity and its ability to quantify the effects of the fuel price and economic activity on the fuel demand, while incorporating the effects of interfuel substitution, fuel environmental desirability, and technological improvements, through the coefficients "b", "c" and "d".

The price elasticity coefficient "b", assigned a range of values of -0.10 to -0.35 for different refinery products (Appendix B), reflects the effect of fuel prices on fuel demand. The more negative the coefficient, the more sensitive is the fuel to the change in oil prices and the more substitutability would be assumed for the fuel. For example, the price elasticity coefficient used for heavy fuel oil is 3.5 times more negative than for gasoline.

The income elasticity coefficient "c", with a range of 0.20 to 0.40, reflects the effect of the economy on fuel demand. The lower the coefficient, the less sensitive is the fuel demand to the change in economic activity. The income elasticity coefficient may decrease as a result of the decreased environmental desirability of the fuel. Also, significant technological breakthroughs bringing about higher utilization efficiency for fuels would result in reduction of the fuel income elasticity coefficient.

The speed-of-adjustment coefficient "d", with a range of values 0.30 to 0.60, accounts for the delay that would be observed between the time of a change in fuel prices and the change in demand. The delay could be due to the required change in capital stock, slow consumer reaction, etc. The closer the coefficient value to 1.0 the faster would be the demand adjustment (more short-term effect) and the lesser the effect would be of the current year change on the long-term demand. For example, in cases where consumers can switch quickly between fuels (dual fuel capability boilers), the speed-of-adjustment coefficient would be close to 1.0.

There are a number of shortcomings with the way the model has been applied here. The model is static in its parameters, i.e. coefficients do not change with time, and do not account for all cross-correlation effects on fuel demand, i.e. the model assumes that the demand for refinery products is independent of other fuel prices. The model assumes symmetry in price elasticity, i.e. the same effect whether prices increase or decrease by specified amount. The model is also somewhat sensitive to the value for each coefficient as depicted in Figure 3.

In addition to modelling the fuel demand and prices, we also projected crude oil and natural gas supply for each learning scenario. We assumed that supply would respond to crude oil

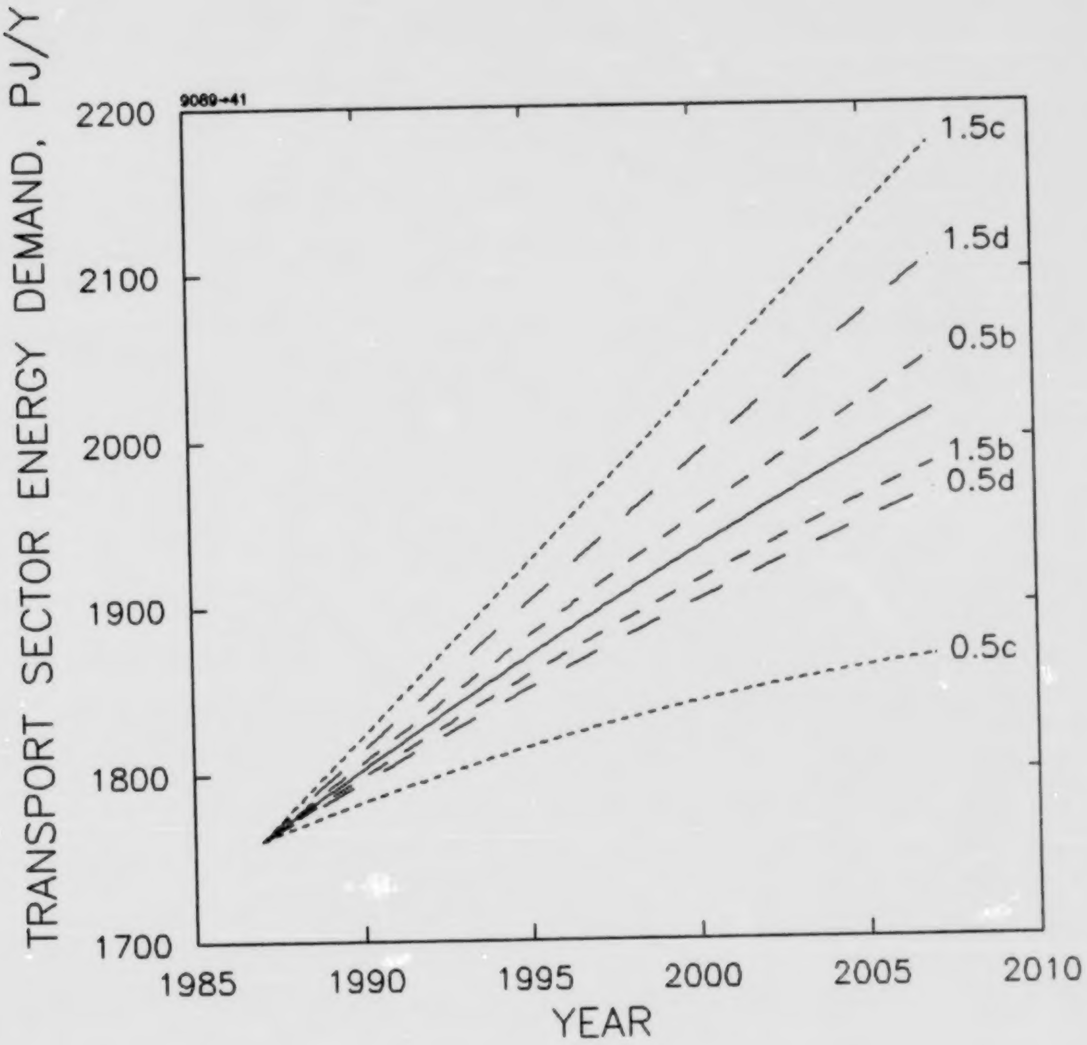


Figure 3. **SENSITIVITY OF THE DEMAND MODEL TO MODEL'S COEFFICIENTS**

prices and GDP growth. The projected volumes for the supply of conventional crude oil, natural gas, frontier oil, etc., were based on supply forecasts developed by the NEB (1988), GRI (1988), AERCB (1988), and other sources, for similar world crude oil prices and economic growth.

2.3. Relevant Issues in Planning R&D

The relevant R&D issues can be classified into: 1) external issues which usually can not be controlled or influenced by an organization such as market demand and supply, environmental or regulatory factors, government policies, etc.; 2) organizational issues which are considered within the organizational framework such as business goals, business strategic view of the future, etc.; and 3) R&D project management issues related to R&D planning and evaluation, R&D strategic factors (checklist), profitability measures and risk assessment methods used.

The external factors such as market, regulatory environment, etc., are part of the development of the scenario analysis framework. The framework provides an understanding of the interrelation of market and supply, the economy, technology and regulatory and environmental policies. The R&D planner can use information provided by the scenario analysis to help identify strategic goals and benefits of energy R&D. The key external issues that are important to planning R&D strategies include:

1. Economic parameters including information on GDP growth, world economic growth and world oil prices, government economic policies, international trade barriers and arrangements, etc.
2. Availability and price of energy including cost of imported oil, potential production of natural gas, conventional and frontier crude oil, level of natural gas exports, etc.
3. Fuel interchangeability addressing relative fuel pricing, impact of environmental regulations, technological developments, government policies or fuel switch, etc.

4. Environmental concerns including environmental initiatives and constraints, their impact on energy production and use, requirements for transportation fuels characteristics, etc.
5. Government involvement in the economy and energy markets, government taxation and deregulation policies, etc.
6. Structural changes in energy supply and demand market including any change in energy industry investment pattern, the effect of environmental factors on energy utilization and fuel substitutability, the effect of conservation and increase efficiency on energy demand, etc.
7. Uncertainty in world oil prices, dislocations in the economic growth, change in public perspective and priorities, etc.

The relevant organizational and R&D management issues in planning R&D projects are discussed in Appendix C. The key organizational issues identified are:

1. Business strategic view of the future and its markets.
2. Business strategic goals, its market position and technological standing, its adapted approach to dealing with competition, etc.
3. The constraints of the R&D portfolio such as resource allocation for near and long-term research, constraints of the existing facilities, staff expertise, etc.

These issues would decide whether a selected project is appropriate from an organizational perspective.

The third group of relevant issues in R&D planning involves R&D management matters. Among those are human resources issues, facilities and capital, and management techniques required at different project stages, project screening and ranking criteria, and the importance of continuity and interaction between different R&D groups. Examples of R&D management issues are presented in Appendix C.

In terms of strategic R&D planning, the key management issue is the formulation of clear, unambiguous project screening and evaluation criteria which would reflect the organizational goals and the external business factors. One such method of formulating evaluation criteria is an R&D checklist. The R&D checklist or Strategic Factors List provides a simple list of questions which address the opportunities (markets, access to feedstocks, etc.) and constraints (competing fuels, implementation barriers, etc.) for the technologies and projects considered. An R&D checklist, based on the learning scenarios could be developed, to describe the opportunities and constraints of natural gas conversion to fuels or fuel components. A general example of the R&D checklist used is depicted in Table 2.

Table 2. R&D CHECKLIST FOR NATURAL GAS CONVERSION PROJECT EVALUATION

Does the proposed project address:

1. OPPORTUNITIES
   - New market and fuel characteristics
   - Projected market size, timing and prices

2. CONSTRAINTS
   - Availability of feedstock (natural gas)
   - Competitive fuels and sources of chemicals
   - Regulatory and environmental concerns
   - Implementation barriers

3.0. TREND ANALYSIS AND VARIABLES AFFECTING CANADIAN ENERGY DEMAND

The data that was reviewed for Canadian energy supply and demand covered the period 1965 - 1985. The main sources of information were Energy Mines and Resources, Stats Canada, the National Energy Board, the Alberta Energy Resources Conservation Board, the Canadian Gas Association and the Canadian Petroleum Association. The diskettes containing the data are described in Section 5, Volume 2 of this Report. The background paper on market constraints for the various end-use markets is contained in Section 2, Volume 2 of this Report.

3.1. General Overview

The perception of Canadian energy reserves and markets has undergone significant changes in the last two decades. The oil price shocks of 1973 and 1979 provided the impetus for technological changes and the implementation of conservation measures which resulted in significant improvements on Canada's energy use.

During the latter half of the 1970's, perceived energy shortages, the control of world oil markets by OPEC and substantial increases in the value of Canada's energy resources encouraged a much greater degree of direct government involvement in the energy sector of the Canadian economy at both provincial and federal levels.

The post-1980 energy market environment has been dramatically different. There has been a large oversupply of oil in world markets and OPEC has a much diminished market position. Natural gas supplies in the North American market have also exceeded demand. This resulted from exploration and drilling programs that were accelerated to meet an energy shortage which instead were met by a major recession which significantly curtailed demand. As a result, both oil and gas prices have dropped significantly. However, the sustained drop in oil and natural gas prices does not appear to have stimulated a major trend toward increased energy use in Canada.

Coincident with the 1980's oversupply of oil and gas, there has been a lessening of governmental regulation and control of the energy sector. Also, a much greater public awareness of the environmental impacts of energy production and consumption on a global basis has developed. This has resulted in an increasing emphasis by governments on the public safety and pollution control aspects of energy projects and energy consumption.

Energy requirements in Canada today are being supplied from a multiplicity of sources with less reliance on oil and increased reliance on natural gas, electricity and coal. The Canadian energy market is basically deregulated interprovincially and for the most part the energy sector already operates in a free-trade environment with the United States.

During the period 1965 - 1985, Canadian energy consumption increased from 4369 PJ to 7762 PJ. (CPA, 1988) At the same time, Canadian GDP increased from $175.3 billion to $393.8 billion in 1981 dollars. (Stats Canada)

The growth of Canadian energy consumption exhibited two marked dislocations following the 1974 - 1975 and the 1980 - 1981 recessions. However, the 1973 and the 1978 oil price shocks affected the overall energy demand in Canada much less than it affected demand in other western countries. This may have resulted because of government regulation which kept crude oil and natural gas prices lower than world prices over that period, and because Canada has a relative abundance of alternate energy sources.

The pattern of energy demand versus GDP for this time period shows that with the exception of the two dislocations, energy consumption parallels the change in GDP (see Volume II, page 2-2). The ratio of growth in energy consumption to GDP has decreased since 1970, reflecting structural changes in the energy use patterns in the economy. More efficient use is being made of the energy consumed and a larger portion of the Canadian economy is engaged in high-tech and service industries which are less energy intensive than Canada's traditional smoke-stack industries (Section 2, Volume 2 of this Report).

3.1.1. Transportation Fuels

During the period from 1965 - 1985, consumption of transportation fuels increased from 1019 PJ to 1610 PJ. (Stats Canada) Over the same timeframe, oil use became increasingly dedicated to transportation purposes because it is the major market area in which economic substitutes are not readily available.

From 1973 to 1980, total transportation energy demand increased at an annual rate of 3.5 percent with road transport increasing 4 percent annually. From 1980 to 1986, total demand for energy in the transportation sector decreased by an average of 2.4 percent annually, with road transport decreasing by 2.5 percent annually. (NEB, 1988)

The decreases in transportation energy demand resulted from the world oil price shocks of the 1970's, increased vehicle efficiencies in the post-1976 period and the general recession of the early 1980's.

The use of transportation fuels is very dependent on new car efficiencies, which have improved significantly over the last 15 years. Fuel efficiencies for trucks have improved, but not as dramatically as for cars. The overall car stock fuel efficiency increased from about 16 miles per gallon in 1974 to 28 miles per gallon in 1986 (Section 3, Volume 2 of this Report).

It is interesting to note that despite the regulatory constraints implementing domestic ceiling prices on Canadian crude oil in the 1970's and early 1980's, Canadian gasoline prices have followed changes in world oil prices.

Canadian gasoline consumption also responded to changes in the growth of the GDP over this period. In the late 1970's, gasoline prices increased and the rate of growth in GDP slowed down, and the consumption of gasoline decreased significantly. However, when the growth in GDP picked up in 1983, the decline in gasoline consumption levelled off and since 1985 has increased indicating a return to market fundamentals. (Section 2, Volume 2 of this Report)

Emissions from gasoline and diesel powered vehicles cause acid rain and contribute to the build-up of carbon dioxide in the atmosphere. However, substitute fuels in most cases do not fare much better.

Lead will be banned as a gasoline additive in Canada by 1990 and in the United States by 1992. This octane enhancer must be replaced with other additives which may have their own environmental problems, or the fuel itself must be upgraded. Fuel upgrading has the effect of reducing refining capacity because of the need to increase the processing severity. Either way, the cost of producing gasoline is increased for the refiner.

The transportation fuel market is the most vulnerable of all Canadian markets to the fluctuation in prices and the supply/demand pattern of world oil. Canada is not self-sufficient in light crude oils and this is the feedstock used by all but one of Canadian refineries for transportation fuels.

Canada's reserves of conventional light crude oils are being depleted at a rate faster than new reserves are being added. Without either significant additional synthetic crude production and additional refining capacity for heavy oil feedstocks, Canada will become increasingly more reliant on imported light crude oils and refined petroleum products. (Section 1, Volume 2 of this Report)

In the short term, propane, compressed natural gas and methanol-ethanol gasoline blends are the alternates to gasoline and diesel powered cars and trucks. In the medium to longer term, batteries, electrolytic hydrogen and the conversion of natural gas to liquid fuels such as methanol and MTBE, are likely scenarios to complement gasoline and diesel fuels from conventional, synthetic and heavy crude oils. However, considerable development work has to be done on the production, storage and utilization of new fuels. Not the least of the tasks is the development of engines that can use new liquid fuels efficiently.

3.1.2. Heating Oil

Heating oil, which includes heavy oil used in industrial boilers and fuel oil in residential and commercial furnaces, has decreased from 1033 PJ to 503 PJ over the 1965 - 1985 period. As a percentage of total refinery products output, heavy and light fuel oil decreased from a combined 37 percent of refinery output in 1965 to less than 18 percent in 1985. (CPA, 1988) Should this trend continue, the combined output of fuel oil would decrease to less than 8 to 10 percent of refinery output by 1990.

During the 1970's and early 1980's, various levels of governments had programs to switch consumers from heating oil to alternate fuels, as well as programs to increase building insulation and to replace inefficient industrial equipment with more efficient equipment. Paradoxically, the federal government also set Canadian oil prices below world oil prices from 1973 to the first part of the 1980's which, in general, distorted the prices for refined oil products such as heating oil.

In the residential sector, 85 percent of energy is used for space and water heating, of which 51 percent is supplied by natural gas and 7 percent by kerosene and light fuel oil. (NEB, 1986) The rest of the energy consumed is supplied by electricity.

In the commercial sector, two-thirds of energy is used for heating and cooling buildings. The relative share supplied by competing forms of energy is approximately the same as for the residential sector.

In-so-far as fuel oil is concerned for residential and commercial space heating, the replacement of old furnaces with more efficient new furnaces, upgrading building insulation, the addition of newer, more energy efficient buildings, microprocessors to control a buildings energy use, etc. have all contributed to a decrease in demand. This trend will continue, no matter the fuel of choice.

The use of oil as a source of energy for space heating will continue to decline simply because of the continued effects of conservation inspired by the 1970's oil price shocks, and, for the most part, readily available and cheaper alternates in the form of natural gas and electricity.

3.1.3. Electricity

Consumption of electricity in Canada increased from 518 PJ to 1336 PJ over the period 1965 - 1985. (Stats Canada)

The production of electrical energy over this timeframe followed changes in the GDP. There was a steady increase in electric energy production with the exceptions of the 1973 - 1974 and the 1978 - 1981 periods when a decrease in GDP reduced the demand for electricity. (Section 2, Volume 2 of this Report)

It is interesting to note that the production of electricity and industrial consumption have both increased substantially since 1980 and in several parts of the country utilities are beginning to worry about adequate generating capacity. Capacity additions, whether nuclear, hydro or coal-fired have long lead times in the order of 10 to 15 years. Only smaller natural gas-fired generating facilities have relatively short lead times in the order of 2 years.

The pattern of use of fossil fuels for the generation of electricity in Canada has changed over the last twenty years. The use of coal has increased significantly with the amount of electricity generated from coal increasing from 15.7 Twhrs in 1965 to 81 Twhrs in 1985. (CGA, 1986)

The pattern of electricity generation from natural gas and petroleum shows different trends during this timeframe. Up until 1975, as prices for natural gas and petroleum remained relatively low, the amount of both fuels used for the generation of electricity increased. However, as the prices for natural gas and petroleum escalated after 1975, the use of both fuels for power production rapidly declined. (Section 2, Volume 2 of this Report)

There do not appear to be any significant constraints to electricity increasing its percentage of final energy demand in Canada or to a continued growth in the amount of electricity exported to the United States.

3.1.4. Coal

The demand for coal in Canada increased from 660 PJ in 1965 to 1133 PJ in 1985. However, with decreasing oil and gas prices after 1985, the demand for coal as a percentage of total Canadian energy use has also decreased. These demand figures include coal used for electrical generation as well as industrial and residential uses (CGA, 1986).

In the industrial sector, coal use decreased from 228 PJ in 1965 to 46 PJ in 1985. The importance of coal as an energy source in industry diminished during the 1950's and 1960's due to the increasing use of lower priced and more convenient energy forms provided by oil and gas. However, interest in coal reversed after the rapid escalation in oil prices during the 1970's (Stats Canada).

The production of coal has increased in Canada every year since 1969 so that by 1985 it accounted for 15 percent of Canada's primary energy production. (Stats Canada).

In Canada, the use of coal as a primary energy source is predominantly for the generation of electricity. In-so-far as the effects of economic growth affect the requirements for electricity, so will the amount of coal required for electrical generation be affected, particularly so in western Canada.

Though constrained by environmental considerations and market prices in most parts of the country opposite natural gas and heavy fuel oil, the use of coal as a cheap boiler fuel cannot be ignored. The proximity of massive U.S. coal reserves with falling unit costs of production could create a competitive industrial boiler fuel market in eastern Canada should world oil prices recover.

In addition to the market constraint of pricing opposite natural gas and fuel oil, coal is generally perceived to be a "dirty" fuel, which has significant material handling problems associated with its use. The emission problems from coal burning are several; carbon dioxide, nitrous oxides and sulfur dioxide as well as the disposal of scrub slurries and dry ash byproducts from stack gas cleaning operations.

3.1.5. Petrochemicals

In 1986, the total requirements for petrochemical feedstocks were 375 PJ of which 149 PJ came from natural gas, 99 PJ from natural gas liquids and 127 PJ from oil. (NEB, 1988)

The growth in the petrochemicals industry in Alberta has been due to the availability of ethane, propane and butane from natural gas production. By 1986, 60 percent of the petrochemical feedstock demand was in Alberta, and 60 percent of the total feedstock requirement was being met by natural gas or natural gas liquids. (NEB, 1988)

Eastern Canadian petrochemical plants were primarily based on oil derived feedstocks. However, with the significant increases in world oil prices during the 1970's, plants in eastern Canada increased their ability to switch from oil to ethane, propane and butane from western Canada.

Over the longer term, ethane demand in Canada will be dominated by petrochemical feedstock requirements.

3.1.6. Natural Gas

During the period 1965 - 1985, consumption of natural gas increased from 778 PJ to 1763 PJ. The consumption in eastern Canada increased from 35 PJ to 185 PJ, in Ontario it increased from 256 PJ to 740 PJ and in western Canada it increased from 487 PJ to 838 PJ. (Stats Canada)

In terms of percentage of Canadian energy use, in 1965, natural gas provided 13 percent of the final energy demand in Canada. By 1975, it provided 22 percent of the final energy demand, and by 1985, it provided over 25 percent. The industrial sector has historically been the largest consumer of gas utilizing over 50 percent of all natural gas usage during this timeframe. (CGA, 1986)

Changes in residential and commercial furnace efficiencies, better building insulation, new industrial processes and new technologies have all had an impact on decreasing the demand for natural gas. However, the federal government's off-oil programs increased the demand for gas at the expense of oil. In addition, natural gas distribution networks were extended throughout rural areas in Alberta and Saskatchewan by provincial governments and eastward through Quebec by private utilities.

The use of natural gas as a feedstock for the petrochemical industry increased significantly during this period.

Natural gas prices have been relatively insensitive to world oil prices since deregulation of the gas industry in Canada and North America in the mid-1980's, due to the oversupply of gas relative to market demand.

The drop in world oil prices during the 1980's has intensified the burner tip competition between natural gas and heavy fuel oil. However, interfuel competition in Canada is not as intense as it is in the United States.

Canadian industry, for the most part, does not have the capability to switch fuels as readily as in the United States. Further, in the residential and commercial sectors, natural gas is generally the preferred fuel for space heating and the penetration of natural gas supply to Canada's building stock is quite high. In areas where there is interfuel competition with gas, it is with electrical power.

As of November 1, 1986, federal government regulations on the export of natural gas to the United States were relaxed and by 1988 export volumes returned to the levels of the early 1970's. Export volumes have since reached new peaks, and the constraint on increased export volumes is one of pipeline capacity, particularly to the California and eastern United States' markets.

3.2. Key Factors in Natural Gas Demand

Stage 2 of the project began with the preparation of a complete list of all of the variables that could be identified as affecting the energy supply and demand situation in Canada. The list was assembled according to the various end-use markets discussed in Section 3.0 of this Report, and then categorized as technological, environmental, or social/political/economic variables. The list of variables affecting Canadian energy supply and demand is contained in Appendix A to Volume 1 of this Report.

The variables which affect the demand for natural gas in Canada were then taken from the list and grouped to identify key factors. These factors are the key factors which should be considered when assessing future changes in natural gas usage within the Canadian economy:

3.2.1. Availability and Price of Natural Gas

Established gas reserves from Canada's conventional and frontier regions are more than twice as large, on an oil equivalent basis, as Canada's crude oil reserves. In addition, there are significant additional gas resources in both Canada and the United States which can be brought into production given high enough market prices.

The commercial terms for the sale of natural gas and for oil are established today in a market-oriented environment. With market forces setting prices for oil and natural gas, the relative economics of each individual fuel supply decision will determine the energy supply mix for the country. This is in contrast to a situation where governments manipulate variables such as supplies and market prices in an attempt to achieve a desired change in the energy supply mix.

With market-oriented pricing mechanisms, responses to changes in the relative pricing of alternate energy forms will be more rapid due to the absence of "regulatory lag", and the responses will likely be different than under a regulated pricing system.

The price of oil is determined by international supply and demand factors which are beyond Canada's control. The price of natural gas in Canada will be set by the demand in Canada and for export to the United States, and by the incremental costs of supplying gas to the marketplace from Canadian reserves.

Natural gas enjoys a competitive pricing edge in most markets over oil and some upward movement in natural gas prices could occur without affecting the competitive balance. Incremental supplies from Canadian reserves will become more costly, and as the supply and demand balance tightens, prices will rise and will begin to reflect the cost of the addition of new reserves.

The conventional natural gas markets in most parts of Canada and the United States are relatively mature. Pipeline infrastructures have been in place for some time and, for the most part, have been fully depreciated. The transportation costs from established production areas to conventional markets are therefore relatively low.

3.2.2. Efficiencies in Existing End-Use Applications

The implementation of currently available technology will continue to improve the efficiency of natural gas usage and this will serve as a "brake" on the growth rate in gas usage in conventional residential, commercial and industrial applications. Also, growth within the existing conventional thermal market areas will be very limited because the market penetration of gas is already very high.

The productivity and technological base of the Canadian petrochemical industry should keep it competitive with the United States in terms of efficiency. The major competition for Canadian producers will be in export markets from the Middle East and other third world countries with secure, low cost feedstocks.

Given higher capital and operating costs, and higher transportation costs from the location of Canadian gas reserves to the heavily populated areas of North America, the production of petrochemicals in Canada for both domestic and export markets will be very sensitive to the comparative feedstock prices of world oil versus Canadian natural gas.

3.2.3. Fuel Interchangeabilities

In most parts of Canada, several alternate sources of economical and reliable energy are available for any given application. In general, electricity is the most expensive energy source, followed by oil and petroleum products, then natural gas and finally coal.

Although coal is often the lowest cost alternative on an energy content basis, the significant capital and operating costs, along with growing environmental difficulties associated with its use, make coal a seldom used option except in very large volume specialized applications such as electrical power generation.

Most of the natural gas that is consumed in Canada is used in combustion applications. The burner tip price of natural gas versus the price of its near substitutes will determine whether an initial installation will be natural gas, fuel oil, electrical or, in some cases, coal-fired.

The large majority of heating systems in Canada are designed for only one fuel source and once a heating system is installed it normally will not be replaced until its useful mechanical life is over. Because of price in most parts of the country natural gas is the fuel of choice for heating applications. As such, the price elasticity for natural gas in these applications is relatively low.

Fuel interchangeability in the industrial market is more sensitive to the relative burner tip price of near alternatives. As noted earlier, Canadian industry does not have as much dual-firing capabilities as U.S. industry. However, a trend towards greater industrial fuel diversification capabilities can be expected for Canada. As fuel diversification capabilities increase and the price of natural gas moves up relative to petroleum products, interfuel competition in the industrial market will increase.

One area where coal and natural gas will compete directly in future is for the generation of steam or as a source of hydrogen for bitumen recovery and heavy oil upgrading.

3.2.4. Government Involvement in the Economy

The degree of government involvement in the Canadian economy and in the energy industry in particular is an important factor to be considered.

From the early 1950's to the early 1980's, government involvement in the oil and gas sectors went from a "hands-off" free market approach to one of significant regulation, increased public ownership and direct intervention in the marketplace. Since 1983, the government approach has been reversed and the movement has been towards deregulation, privatization and allowing market forces to prevail.

Government policies have been used in the marketplace to encourage conservation and efficiency improvements and to switch between fuels. However, government regulation and subsidies do distort energy prices to the end-user and the result can be wrong or inappropriate signals to the marketplace.

The clear direction for regulation and government intervention in the North American marketplace is for less government involvement. This helps to eliminate regulatory lag and possible mixed pricing signals which will be plus factors given volatile international energy markets and Canada's free trade agreement with the United States. However, private industry and the international marketplace do not always function in the best interests of society in general.

As long as the supply/demand balances for the world's energy requirements stay relatively in line, the political will for government intervention in Canada will continue to wane. However, if a significant disruption in the supply/demand balance occurs, regulation and government intervention in the Canadian marketplace will quickly return.

The degree of government involvement in the economic aspects of the energy industry will affect Canada's energy supply mix, the prices paid for energy by end-users, and the ease or difficulties with which transitions can be made to accommodate sudden and severe changes in international energy markets.

Government involvement will continue in areas such as research and development and in the environmental and safety aspects of the energy industry. In addition, governments will continue to play a role in the facilitation of mega-projects which are beyond the normal risk-taking capabilities of private industry.

3.2.5. Environmental Concerns

Environmental issues that effect energy consumption in Canada are global in nature - i.e., acid rain, carbon dioxide build-up in the atmosphere and the attendant "greenhouse" effect, ozone layer depletion and pollution of the oceans.

The cleanest of the conventional hydrocarbon fuels is natural gas, but even natural gas releases carbon dioxide when it is burned. If the greenhouse effect were to become a global crises that required severe curtailment of fossil fuel combustion, natural gas would still be the preferred hydrocarbon fuel relative to oil and coal.

Major structural changes would be required in the Canadian economy to effect significant enough gains in energy-use efficiency and conservation to lower carbon dioxide emissions.

There is also a growing recognition of the need to work towards a global economy based on "sustainable development" and of the impact that this has on the quantity and types of energy demands. The impact for Canada will be lowered levels of energy demand, less hydrocarbon usage and more electrotechnologies on a relative basis.

The elimination of lead from gasoline and increasing environmental problems with emissions from motor vehicles, particularly from diesel fuels, provides an opportunity for the increased use of natural gas based products such as methanol and MTBE in liquid fuels. In addition, compressed natural gas offers significant advantages over all other fuel options from the point of view of reduced carbon dioxide, hydrocarbon and particulates emissions.

3.2.6. Economic Parameters

Canada has a relatively open economy and changes in economic activity and its effect on energy consumption for the most part will be established not by Canadian policy but rather by international conditions. Further, changes in the energy consumption by the various sectors of the Canadian economy are primarily driven by changes in the country's GDP.

As such, generally healthy world economic conditions or problems with the world's major economies will be transferable directly back to the Canadian natural gas marketplace.

The performance of the Canadian economy in terms of productivity will be important in the global marketplace. In addition, balance of trade problems and third world debt problems will increasingly affect Canada's open economy.

In terms of a single economic parameter, the rate of change in Canada's GDP will reflect both world market conditions and the relative performance of the Canadian economy.

3.2.7. Structural Changes

The oil price shocks of the 1970's caused significant structural changes in the Canadian economy. The oil price shocks resulted in the more efficient use of energy per unit of economic output thus demonstrating that economic growth is not necessarily dependant on an equivalent growth in energy consumption.

The oil price shocks of the 1970's also demonstrated that there is a significant time-lag between the occurrence of a dislocation to the economy and the effects of any actions taken as a result of the dislocation. For example, even 10 years after the last oil price shock there continues to be significant increases in efficiencies in all forms of energy use.

Part of the reason for the time-lag is that conservation efforts take time, even for the implementation of currently available technology. In instances where new technology is required, the time-lag may be in the order of 10 to 15 years for technologies to be developed through applied research and market implementation.

The effect on resource development also takes time. Following the energy shocks, government policies encouraged activities in conventional oil and gas resource developments, frontier and offshore developments, non-conventional forms of energy, etc. The significant world recession and surplus energy supplies of the early 1980's did not immediately put a halt to the effects of these government programs. For example, oil reserve additions accelerated in Canada during a period of rapidly declining energy demand.

The time lag with respect to new resource development is an important consideration. For the utilization of energy from proven oil and gas reserves in frontier areas, for a given project to proceed, lead times in the order of 8 to 10 years are currently required.

Shocks, or dislocations, to the economic system in the next two decades could take several forms. However, it is the magnitude and the "personal" impact of a dislocation that will affect the speed of society's response and the amount of political will and resources that can be dedicated to react to the situation.

4.0. ALTERNATIVE SCENARIOS

4.1. Canada Today and Tomorrow

This Section provides an introduction to the alternative scenario descriptions. All of the scenarios begin with the same energy supply and demand situation which is Canada Today. As such, the following description is our perception of the current Canadian energy supply, environmental and economic situation.

4.1.1. Energy Supply Situation

Oil

A surplus of productive capacity for oil exists on the world market. OPEC does not have control of the world market and the supply of oil available from non-OPEC sources continues to increase. OPEC is having trouble maintaining the price of oil in the \$15 - \$18/bbl range (\$US, 1987). The low oil prices of the last several years have not triggered an increase in world oil demand.

The price of oil in Canada is deregulated and is set by world oil prices and not by Canadian supply costs. Canada's supplies of conventional crude is being depleted at a rate faster than it is being replaced. The fastest growing source of oil in Canada over the last five years has been from bitumen. However, the level of imports of foreign oil into Canada have grown both in absolute numbers and as a percentage of total oil supplies.

Oil in Canada has been increasingly dedicated to transportation end uses with light fuel oil and kerosene uses declining. Heavy fuel oil competes with natural gas in the switchable industrial markets.

Natural Gas

A surplus of productive capacity exists for natural gas in the North American market. This surplus has existed for a number of years and is only now coming into balance with demand. The main reason for the realignment of supply and demand is an increase in the utilization of natural gas at the expense of heavy fuel oil and coal primarily in the United States market. The levels of exports to the United States are at historic highs and are currently limited by the availability of pipeline capacity to various parts of the United States market.

The price of gas is set by supply and demand conditions in North America. Gas is currently priced low relative to oil and is being sold in a number of instances at below replacement cost. However, Canada currently has a large, reliable and secure source of gas supply. The penetration of gas into conventional domestic markets is high.

Electricity

Canada has a very diversified electrical generation base across the country. Significant amounts of hydro-electricity is either being exported to the United States or the generation and transmission facilities necessary to increase the amount of electrical power exported are being developed.

In addition to hydro power, significant amounts of electricity is generated by coal and nuclear energy. The resource base, the transmission facilities and the technical capabilities that exist within the country would allow Canada to significantly increase the amount of electricity used relative to other forms of energy.

However, electricity is generally the most expensive form of energy in Canada. In addition, most utilities across the country are recognizing that a shortage of generating capacity could occur within the next decade.

Hydro power is usually regarded as a clean energy source which could be to its advantage in the contest of an environmentally driven energy base. However, there is a need to determine the impact of the flooded areas on the greenhouse effect.

Coal

Canada has very significant reserves of low cost thermal and metallurgical coal. During the last decade, coal has regained some of the stature that it lost as a source of energy with the advent of cheap oil and gas supplies.

Although coal is generally the lowest cost alternative in Canada on an energy content basis, the significant capital and operating costs associated with its use, in addition to the environmental difficulties associated with its use, make it a seldom used option. The main exception is the use of coal for electrical power generation.

4.1.2. Environmental Situation

Canadian society is becoming more conscious of environmental issues. The reduction of emissions from automobiles has been underway for more than a decade now. Canada is requiring the complete elimination of lead from gasoline by the end of 1990. Acid rain, the depletion of the ozone layer and the build-up of carbon dioxide in the world's atmosphere are issues of international importance and Canada is taking action to improve its record with respect to these problems.

The rapid development of some of the third world nations is causing concern as to who will pay for the environmental controls in developing nations.

4.1.3. Economic Situation

The major world economies have experienced a period of sustained growth over the last seven years. However, much of the growth has been funded by government deficits, particularly in North America and third world countries. Large trade deficits also plague these latter economies. Real interest rates are high by historic standards. Restrictive trade practices and monetary policies are emerging on a number of fronts.

Canada has an open economy and international economic conditions directly affect the potential for the Canadian economy. Canada is in the initial stages of implementing a free-trade agreement with the United States and this will further tie Canadian fortunes to the performance of the United States and world economies.

There is a continuing movement towards deregulation of energy markets and a movement towards a continental market for natural gas, oil, coal and electricity.

Canada has been experiencing high real interest rates for well over a decade, and with the exception of Ontario, generally high unemployment rates. The large budget deficits that exist at the federal and provincial levels limit the ability of the respective governments to implement policies and programs. However, all levels of government in Canada appear to be committed to protecting the environment and to developing a diversified energy supply base.

4.1.4. Current Energy Demand by Different Sectors

Tables 3 and 4 show the energy demand in Canada for the year 1986 according to major energy form and according to energy demand by sector (Residential, Commercial, Industrial, Agriculture and Transportation Fuels).

4.1.5. Predetermined Elements

In scenario analysis, it is important to identify as many of the elements for the situation that are "predetermined". By predetermined is meant those events that have already occurred, or which almost certainly will occur, but whose consequences have not yet unfolded. The predetermined elements will therefore exist in each of the scenario alternatives but the consequences of the elements may differ.

The following predetermined elements have been identified for Canada Tomorrow:

- the United States has a post-industrial type economy and Canada will become more like the United States, i.e., a service oriented, high-tech economy.
- economic growth in Canada is not dependant on an equivalent growth (by historic standards) in energy consumption.
- low world oil prices will not in themselves fuel increased economic activity.

Table 3. DISTRIBUTION OF END ENERGY USE BY MARKET SECTOR (CANADA, 1986, PERCENT*)

MARKET	COAL	NATURAL GAS	ELECT.	GASOLINE	KEROSENE LIGHT FUEL	DIESEL	HEAVY FUEL OIL	AVIATION GASOLINE
Industrial	3	49	43	--	<0.1	2	3	---
Transport	---	16	2	54	---	18	3	6
Domestic	<0.1	51	42	--	7	--	<0.1	---
Farm	---	23	40	16	3	18	---	---
Commercial	<0.1	52	41	2	2	3	<0.1	<0.1

*Percent of total energy use by the market sector rounded to the nearest percent.

Table 4. DISTRIBUTION OF THE USE OF DIFFERENT FUELS BY MARKET SECTOR (CANADA, 1986, PERCENT*)

MARKET	COAL	NATURAL GAS	ELECT.	GASOLINE	KEROSENE LIGHT FUEL	DIESEL	HEAVY FUEL OIL	AVIATION GASOLINE
Industrial	92	43	45	--	8	19	70	--
Transport	--	5	1	90	--	55	20	81
Domestic	7	28	28	--	67	--	2	--
Farm	--	1	2	5	4	10	0	--
Commercial	1	23	24	5	21	16	8	19

*Percent of total fuel use by EACH market sector rounded to the nearest percent.

- the changes in economic activity in Canada and its effect on energy consumption will be linked very closely to the general well-being of the world's major economies.
- Canada's economic growth will be closely tied to the fortunes of the United States economy.
- In the absence of the effects of taxation, the price of natural gas and petroleum products will be the same in both the United States and Canada.
- ongoing improvements will be achieved in energy utilization in Canada irrespective of the relative price of energy, resulting from continued technological improvements, conservation measures and the gradual replacement of aging capital stock with newer more efficient alternatives.
- OPEC will not be able to manage the international oil market during the timeframe under consideration in this study.
- North America's reserves of conventional oil and gas are being depleted faster than they are being replaced.
- Canada has a reliable and a secure source of natural gas supply that is available at prices that are competitive with world oil prices.
- Canada has large bitumen and heavy oil resources which are expensive to utilize and which are not competitive with alternative world oil supplies.
- incremental conventional oil and gas supplies in Canada and the United States are becoming progressively more expensive.
- Canada will have to increase oil imports and/or develop its bitumen and heavy oil deposits to make up for the decrease in its conventional oil supplies.
- Canada's use of oil will continue to become more dedicated to transportation end-uses. The consumption of light fuel oil and kerosene will continue to decline.
- natural gas prices will increase relative to the price of oil.
- increases in world oil prices will be determined by the rate of economic growth on a global basis.
- environmental concerns will cause greater conservation efforts to take place and there will be a policy emphasis by governments to address environmental issues.
- natural gas is the preferred hydrocarbon fuel.

- the environmental difficulties associated with the use of coal will make it the least desirable option even in electrical power generation applications.
- there will be more emphasis by governments on research and development to utilize new or better technologies for the production or utilization of conventional energy forms.

The above predetermined elements were used for development of four scenarios along two themes: 1) energy security and diversity theme with High Oil Import and High Resource Development Scenario; and 2) environmental protection and alternatives theme with High Vehicle Efficiency and Non-Petroleum Fuels Scenarios. The major difference between the themes was the level of environmental concern (factor) that was ascribed to future Canadian energy in economic Development activities. The principal difference between the scenarios within each theme was to ascribe levels of gross domestic growth and concurrently the range for oil price increasec (Figure 1). The following sections explore the consequences of each scenario on the Canadian energy demand and supply markets.

4.2. High Oil Import Scenario (HOI)

This scenario was chosen as a base case or reference case because it represents an extension of today's energy situation as we see it in Canada and the world. It can be characterized as a continuation of the status quo with a growing emphasis on environmental concerns.

4.2.1. Economic Parameters

As a continuation of the status quo, Canada's economic growth will follow the world average economic growth of 2 percent per year, over the time-frame under consideration. Large government deficits, trade imbalances, third world debt problems and high real interest rates will continue to characterize the world's economic scene. Trading blocks such as the Canada-U.S. free trade arrangement and the European Community will continue to emerge as will restrictive trade and monetary policies. With Canada's open economy we will share with the U.S. high interest rates, relatively high unemployment rates and relatively high inflation rates.

As a result of constrained economic conditions, world oil demand will grow at a modest rate of 0.3 percent per year and this low growth will keep oil prices in the range of $20 - $24/bbl ($CDN 1987) during the scenario time-frame. The price of oil will increase only as the incremental costs of non-OPEC supply increases. Increased oil demand will result from economic growth but the demand will be tempered by conservation efforts and improved efficiencies.

We expect that the crude oil price volatility and conflicting economic signals will result in a weak investment climate for Canadian energy development in the 1987-2007 period. Also, the Canadian government will be under constant pressure to balance high deficits while dealing with persistent unemployment and inflationary forces, thus facing priorities other than energy development.

4.2.2. Availability and Price of Natural Gas

The availability of natural gas will not be a constraint in this scenario. Sufficient reserves are available to meet domestic requirements and demands for the export market from conventional reserves until about the year 2000. Beyond that date sufficient additional reserves are available from frontier areas and the so-called tight sands formations to meet the forecast requirements at appropriate incremental pricing levels.

Prices for natural gas will rise relative to oil in the short term as supply and demand come into balance. Beyond the early 1990's, the price of natural gas will continue to rise relative to oil in markets where it does not compete directly with oil, i.e. in all markets other than the heavy oil or switchable fuels market. The price rise is necessary because natural gas is currently being sold at less than replacement cost. The price rise is possible because gas is priced well below its near substitutes in its conventional non-industrial markets and gas producers are actively working towards developing new premium market applications for natural gas.

The natural gas prices in this scenario will rise from a fieldgate price of $1.70/GJ in 1987 and will begin to reflect the cost of the addition of frontier reserves from the MacKenzie Delta and Beaufort Sea areas by the late 1990's. Projected field gate prices will reach $2.00/GJ in 1997 and $3.50/GJ in 2007 ($Cdn, 1987).

Canadian exports will supplement U.S. natural gas production. Growth in U.S. production will be impeded more by the low oil prices than Canadian production because of higher replacement costs in the continental United States, Canadian natural gas will find new markets in applications where environmental considerations call for cleaner burning fuels, e.g. the California power industry. Canadian exports in this scenario will increase to about 47 x 10^9 m^3/Y by 1997 and then slow down in the late 1990's and early 2000's, due to persistently low oil prices and the introduction of a combination of conservation measures and new oil combustion technologies.

Canadian natural gas producers will enter a period of relatively stable demand as prices firm during the early 1990's. However, by early 2000, as oil prices remain low, the situation will become more volatile and producers will be reluctant to invest in the further development of natural gas reserves. Persistently low crude oil prices will also have a negative effect on natural gas exploration.

4.2.3. Efficiencies in Existing End-Use Applications

Improvements in efficiencies will continue initially because of the impetus created by the previous decade's oil price shocks. Improvements will also take place because there remains room for efficiency improvements strictly on economic grounds. Additional impetus for efficiency gains will come because of growing pressure to conserve energy as a means of combating environmental problems.

Major efficiency gains are expected in gas and electric equipment due to the replacement of old capital stock with the new stock. As a result, energy demand in the Residential and Commercial sectors will grow at moderate rates of 1.4 and 2.0 percent, annually. Natural gas is expected to further increase its share of Canadian energy demand, although at a slower rate.

4.2.4. Fuel Interchangeabilities

Fuel interchangeabilities in the conventional thermal markets in Canada for oil versus natural gas will not be altered significantly. Changes will, however, occur in those instances where electricity can be considered as a near enough substitute for a switch to be made without too much economic penalty. Coal will become even more of a last choice option in North America for industrial use because of additional costs associated with increased sulfur dioxide and nitrous oxide controls to alleviate environmental concerns (primarily acid rain).

The implications of any movement away from coal for power generation will affect natural gas and oil in essentially the same manner. Natural gas is already being used to a growing extent for power generation in North America because of the current low cost of the fuel, the need for more peaking plants versus base load units as utilities strive to minimize capital expenditures and because of the advent of more natural gas fired co-generation facilities. However, as a swing fuel, natural gas competes with oil and coal as a fuel for large boilers. If there is strong pressure to move towards nuclear power in North America, both oil and gas will be affected.

It should be noted that the time required to bring new nuclear power plants on-line will be in the order of 10 to 15 years and this will only be possible with substantial changes in public perception and the ability of licensing and approval agencies to perform more quickly than in the past.

The impetus for more fuel interchangeability will be evident in the transportation sector. Diesel fuel will become environmentally less acceptable and this will increase the demand for gasoline and other alternative fuels. More stringent emission standards will act as a downward effect on motor vehicle efficiencies, but technological changes and perhaps taxation policies by governments will help keep the lid on a growing demand for transportation fuels.

4.2.5. Environmental Concerns

The global concerns of acid rain, carbon dioxide build-up in the atmosphere and the depletion of the ozone layer will be a pressing factor in this scenario, but the concerns of society in general will not be great enough for the government to make it a number one priority at the expense of other programs. The government will, however, be active in areas where, through legislation, the costs for emission controls, restrictions on resource development etc. can be borne by industry or the general populace without significant or obvious economic dislocations.

Natural gas will be the preferred hydrocarbon fuel and the percentage of Canada's total energy demand that is supplied by natural gas will increase relative to oil and coal.

As a result of growing environmental concerns and government legislative action, this scenario envisions more strict regulations on CO emissions. The scenario incorporates a provision for increasing oxygen levels in gasoline to 2 percent of oxygen to reduce CO emissions in the winter time, and the use of CNG and/or alcohols in place of diesel fuel, at a level equal to 10 percent of the diesel consumption in 2007 on an energy equivalent basis. A 10 percent tax is also factored into the projected diesel prices, starting in 1997. This tax is implemented to offset the tax loss from alternative fuels.

The scenario also incorporates stricter regulations on the volatility of gasoline (about 2 RVP points) to reduce hydrocarbon emissions during the summer months. This will preclude the utilization of alcohols as gasoline additives through-out the year, without the removal of other light hydrocarbons such as butanes from gasoline stocks.

4.2.6. Government Involvement in the Economy

During the initial part of the time-frame for this scenario, the approach of government in Canada will be to maintain its movement towards deregulation, privatization and allowing market forces to prevail. Because Canada has an open economy which is becoming increasingly tied to the U.S., and because of its large budget deficits, government involvement in the energy sector for taxation or economic development reasons will be limited. However, the government will become more involved with both the supply and the demand sides of the energy sector because of environmental issues. With restrictions on how much money is available for the government to spend on technical solutions to the problems, policies will be restricted to tax incentives for conservation or efficiency improvements or for the installation of specialized pollution control equipment.

Direct government funding of R&D activities will decrease and the focus will be on short term projects carried out in collaboration with the private sector. Industry spending on R&D in this scenario of continued low economic growth will be restricted to those areas where profits can be realized over the short-term.

4.2.7. Structural Changes and Key Issues

Because the essence of this scenario is the maintenance of the status quo, no significant structural changes for the Canadian economy are envisioned. The key issues in this scenario are:

- high import levels of light crude oil.
- exports of natural gas to the U.S. are based on free market conditions
- unconventional and frontier natural gas production required by the year 2000.

- development of markets for gasoline extenders (methanol) or octane enhancers (MTBE).
- supply of petrochemicals by Middle East countries rich in natural gas and petroleum reserves.
- potential for the development of policy and regulatory initiatives by the Canadian government to ensure security of oil supply at low prices.

4.2.8. High Oil Import Scenario Results

Tables 5 & 6 depict the projected supply and disposition of light crude oil for the period 1987-2007 and the projected consumption of transportation fuels in Canada. These tables have been prepared using the methodology outlined in Section 2.2 and the assumptions that support this scenario - i.e. low economic growth, low world oil prices, increasing natural gas prices, and no significant changes in energy consumption patterns in Canada with the exception of the effects of government legislation concerning gasoline and diesel emissions.

The most striking feature from the tables is the projected increase in crude oil imports by over 380 percent from 27 x 10^3 m^3/d in 1987 to 99 x 10^3 m^3/d in 2007. At prices of $20 to $24/bbl for oil, the value of the imports will increase from $1.2 billion dollars in 1987 to 5.4 billion in the year 2007 ($Cdn, 1987).

Table 5. CONSUMPTION OF LIGHT CRUDE OIL AND TRANSPORTATION FUELS (HOI), Mm^3/d

	1987	1997	2007
TRANSPORTATION SECTOR	126.5	135	143
Gasoline	90.0	94	98
Middle Dist. (diesel & aviation)	42.7	47	52
HFO	2.6	3	3
TOTAL CANADIAN[1]	197.0	213	229

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[1] excludes consumption (7.5%)

Table 6. SUPPLY AND DISPOSITION OF LIGHT CRUDE OIL (HOI), Mm^3/d

	1987	1997	2007
PRODUCTION CAPACITY			
Conventional[1]	195	160	130
Synthetic[2]	29	50	50
SUBTOTAL	224	210	180
DOMESTIC SUPPLY[3]	186	174	149
TOTAL DOMESTIC REQUIREMENT[4]	213	230	248
NET IMPORT REQUIREMENT[5]	27	56	99

[1] NEB (1988)

[2] COOP + BI-PROVINCIAL & SYNCRUDE UPGRADE (8+7+6 Mm^3/d)

[3] At 83% of production capacity

[4] STATS CANADA 213 Mm^3/d vs NEB 202 Mm^3/d

[5] does not consider alternative fuels production

The large increase in oil imports is consistent with the theme of this scenario. Low oil prices will not support development by industry of Canada's bitumen and heavy oil deposits nor will it encourage tertiary oil recovery projects if the expected returns are low. Conventional oil reserves will be depleted at a rate faster than they are replaced. Large government deficits will preclude funding for new megaprojects in the northern and offshore areas unless a project has a clear chance of being economically self-sustaining. With non-OPEC oil supplies being sufficient to prevent OPEC from controlling world markets, public opinion will allow governments to let Canada's reliance on oil imports grow.

In an economic environment where growth is low, unemployment, inflation and real interest rates are high, governments will not be able to promote a concept of higher prices for Canadian oil to allow industry to develop marginal or non-conventional reserves for strategic reasons. Also, to maintain international competitiveness of the Canadian industry, energy prices can not be set above world prices.

In this scenario, the total domestic requirement for oil increases but at a rate that sees oil supply a diminishing percentage of Canada's over-all energy requirements. Concurrent with this trend is the continued dedication of oil to provide energy to the transportation sector. Because prices for oil remain low and there are no supply constraints, there are no market forces to provide an impetus for changing to alternate fuels. Continued environmental pressure will however affect the additives and blends used in gasoline and it will cause a decrease in the use of diesel products.

The environmental pressures will create a window of opportunity for natural gas based chemicals that can be used as gasoline additives and blends. Table 7 summarizes the potential for alternative fuels in this scenario. The methanol equivalent rises from the 19.6 kt/y used as a gasoline additive in Canada in 1987 to 1,300 kt/y in 1997 and 3,850 kt/y by 2007.

This window of opportunity will be affected by the ability of Canada's petrochemical industry to compete on a world scale basis. Because of high capital and operating costs, Canadian producers of petrochemicals require an offsetting advantage in terms of feedstock costs to compete with the Middle East. Competing feedstocks will be both oil and natural gas based.

In this respect, the Canadian petrochemical industry will be facing a squeeze because oil will only be available to eastern Canadian producers at world prices and western Canadian producers will see the price of natural gas rise from 90 percent of oil on an energy equivalent basis in 1987 to 109 percent of oil by the year 2007 (Table 8). It will further stress the importance of more efficient technologies for natural gas based petrochemicals.

Table 7. POTENTIAL FOR ALTERNATIVE FUELS (HOI)

	1987	1997	2007
FUEL PRICE			
Oil $/bbl	20.00	21.91	24.00
Gasoline, ¢/L	35	37	40
Diesel, ¢/L	30	35	37
MINIMUM POTENTIAL[1]			
Gasoline, PJ/Y	0.4	12	25
Diesel, PJ/Y	-	19	42
Crude Oil Equivalent, Mm^3/d	-	2	5
Methanol Equivalent, kt/Y	19.6	1,550	3,350

[1] 2% of oxygen in gasoline over 6 winter months by 2007
10% energy equivalent diesel fuel replacement by 2007

Table 8. NATURAL GAS PRODUCTION, EXPORTS AND PRICES (HOI)

	1987	1997	2007
PRODUCTION[1], 10^9 m^3/Y	89.9	122	133
EXPORT[2] 10^9 m^3/Y	27.7	46.5	46.5
PRICES, \$/GJ			
Fieldgate[3]	1.70	2.00	3.50
Toronto[4]	2.95	3.90	4.25

[1] Statistics Canada (1987), NEB (1988) data for domestic demand for year 1997/2007 plus export

[2] Addition of ANR, PGT, Home Oil pipeline to export market (4.3 + 7.3 + 7.2 10^9 m^3/y)

[3] NEB (1988) projection for 1997 and 2007; 1987 Alberta gas price CPA (1988)

[4] industrial users (vs 2007 oil price \$3.93/GJ); 1987 price is an average industrial service in Toronto

The situation for the Canadian petrochemical industry by 2007 will resemble the condition of the U.S. petrochemical industry today, where imports from low cost countries have forced the shutdown of a number of natural gas and oil based plants. It is expected that OPEC countries will continue to develop their petrochemical industries in an effort to increase revenues as crude oil prices remain low. The increased world capacity for petrochemicals will become concentrated in the Middle East and other third world countries with low priced natural gas or oil feedstocks.

Table 9 shows projected prices for methanol and other oil and natural gas based chemicals. For comparison, the current and projected ethylene prices (f.o.b. plant) for the Middle East are between $132 and $176 Cdn per tonne, or two to three times less than the Canadian prices.

The strategies available to Canadian petrochemical producers will be to improve its technology for the production of petrochemicals from both oil and natural gas feedstocks, to direct its production to high value markets, i.e. methanol for MTBE, or to achieve a higher degree of vertical integration which would include natural gas exploration and production to secure long term low cost feedstocks. Vertical integration can often allow for taxation benefits particularly where exploration costs for oil and gas are concerned.

Table 9. PROJECTED PRICES FOR SELECTED PETROCHEMICALS (HOI)

	1987	1997	2007
METHANOL[1], ¢/L	22.6	27	29
ETHYLENE[2], $/tonne	346	462	506
ETHYLENE (Middle East), $/tonne	132	<— 176	—>
METHANOL (fuel)[3], ¢/L	16.3	18	29
BENZENE, $/tonne	386	409	432

[1] calculate using price equation in Appendix B, Toronto natural gas prices, actual ¢21.1/L to ¢24.0/L for 1987

[2] actual $396/tonne to $550/tonne for 1987

[3] based on fieldgate natural gas prices, 15 DCF ROR, 70% feed variable cost; 1987 production cost ¢14/L for $1.40/GJ natural gas (CERI, 1988)

Under the High Oil Import Scenario, natural gas will continue to be used primarily as a source of thermal energy in conventional end use applications. Although prices for natural gas throughout this scenario will be held down by competing energy supplies, the price of natural gas in Canada will rise in relation to oil and oil based products because of increasing replacement costs. Low oil prices will cause significant pressure on natural gas in the swing fuel market. Low economic growth throughout the period will allow efficiency improvements to offset to a great degree increases in demand for natural gas from additional or new applications. Low, yet stable, growth of the U.S. economy will not provide the continuous growth in export markets for Canadian natural gas envisioned by some. Further, environmental pressure will not be great enough to cause a significant movement away from coal and the emphasis will rather be on cleaning up stationary emissions from coal fired plants.

The utilization of natural gas as a source of hydrogen for heavy oil upgrading is also curtailed under this scenario. Because of a reliance on imported oil and refined transportation fuels, the amount of natural gas used for this purpose is not projected to increase significantly beyond that required for the plants currently in operation or on the drawing boards today.

The economic barriers to the increased utilization of natural gas for conversion to alternate fuels or petrochemical products in this scenario can be seen from the following figures for the period 1987 - 2007 (Tables 7, 8 and 9):

- increase in gasoline prices = 14.3%
- increase in diesel prices = 23.3%
- increase in methanol prices = 28.3%
- increase in natural gas prices
  - fieldgate = 105.9%
  - Toronto = 44.1%

The incentives for natural gas conversion in this scenario come primarily from the window of opportunity in the gasoline additive and diesel fuel replacement market.

Methanol's best opportunity for the replacement of gasoline (or imported crude oil), would be in the mid 1990's (¢37/L for gasoline vs ¢36.2/L for methanol). However, as natural gas prices increase in the early 2000's, the increase in methanol production cost would outpace the gasoline price increase, suggesting that any R&D in this area should target the near-term objectives for methanol technology improvement.

The opportunities for the natural gas conversion to fuels and fuel components in the HOI scenario are as follows:

- use of MTBE and other natural gas based oxygenates as gasoline enhancers and as cleaner, less polluting fuels.
- application of CNG and natural gas based fuels for emissions reduction from transit buses in urban areas.

Under the HOI scenario, technologies for the conversion of natural gas to gasoline would be hard pressed to compete with conventional technologies. The constraints on the increased use of natural gas for conversion to alternate fuels in the HOI scenario are as follows:

- significant quantities of low cost light crude oil available to Canadian refiners for refining into transportation fuels.
- environmental concerns are not great enough to cause significant shifts away from current consumption patterns of gasoline diesel fuels and perhaps even coal.
- low economic growth and high government deficits preclude any initiatives by the government on the development of alternate fuels.

4.3. High Resource Development Scenario (HRD)

This scenario was chosen to represent a significant increase in future world oil prices in the absence of any escalation in environmental concerns over the HOI scenario. High world oil prices would be a result of strong world economic growth and a significant increase in demand for oil by third world developing countries.

4.3.1. Economic Parameters

In the High Resource Development (HRD) scenario, Canada's economic growth would follow an average world economic growth rate of 3.0 percent per year over the 1987-2007 period. The growth rate is quite large considering the moderate projected population growth of 0.9 percent per year for Canada over the same time-frame. Such an economic performance will require a major reduction in government deficits, improvements in the trade balance and strong export markets for Canada's resource and agricultural sectors. Strong commodity markets around the world would ease third world debt problems and an open international market place would allow more rapid technology transfer to third world countries and better economic conditions for all nations. The HRD scenario would see significant growth in GDP with moderate inflation, lower unemployment levels and lower interest rates.

As a result of strong world economic growth, world oil demand is expected to increase at an annual rate of 1.3 percent or more, which will require an increase in OPEC oil production from 41 percent of the world oil supply in 1987 to over 50 percent of world supply in 2007 (NEB, 1988). The strong demand for crude oil will also result in an increase in world oil prices from $20/bbl in 1987 to $35/bbl by 2007 (CDN 1987 dollars).

The increase in oil prices will encourage significant investment in Canada's conventional gas and oil producing areas, enhanced oil and gas production techniques, bitumen and synthetic crude oil production and in the development of Canada's frontier resources.

4.3.2. Availability and Price of Natural Gas

The availability of natural gas will not be a constraint within the time period considered. Strong world energy prices will encourage increased natural gas exploration activities and production from conventional and frontier reserves will meet domestic and export requirements. However, the total export and domestic demand is not expected to increase substantially above the HOI scenario level because of increased energy efficiency and conservation in Canada and the U.S. in response to the higher energy prices.

One might expect that under the high oil price scenario, exports of natural gas to the U.S. would increase substantially, reflecting the competitiveness of the Canadian gas versus world oil in U.S. markets. However, with higher oil prices, U.S. domestic gas production would be able to increase significantly. GRI estimates that 20.5 trillion cubic metres of gas could be produced at wellhead prices of \$5.25/GJ (U.S.). This wellhead price is competitive with world oil prices of approximately \$32/bbl (\$Cdn, 1987). Therefore, with higher oil prices, U.S. domestic production will increase enough to keep Canadian exports to the U.S. at a relatively constant level.

It is of interest to compare various current projections of Canadian gas exports to the U.S. for this time-frame (Table 7). For example, GRI expects gas imports to remain static until the mid 1990's. Thereafter, with declining U.S. production, imports would meet increasing U.S. demand. GRI assumes that after the year 2005 Canadian gas imports would be balanced with higher U.S. production. GRI estimates a 1987 Canadian export capacity of 45×10^9 m^3/y vs 27.7×10^9 m^3/y current exports. It also projects that Arctic and offshore Atlantic regions would become available for exports to the U.S. in the late 1990's. It assumes that in the late 1990's two-thirds of the growth in Canadian exports would come from Canada's frontier areas.

CERI export projections are the most optimistic of the forecasts shown (Table 10). CERI's projection would be possible if a combination of factors takes place, i.e. higher oil prices, lower U.S. production and higher Canadian exploration activities due to expected growth in natural gas demand.

The NEB has recently revised its forecasts for natural gas exports from a low of 18.0 x 10^9 m^3/y in the year 2000 to 40.0 x 10^9 m^3/y (Table 10). Several reasons were given for the increased export projects of which the most important are: changes in the U.S. regulatory environment, low incremental cost of Canadian gas in the late 1980's and the early 1990's, and access to Canadian suppliers of some of the available pipeline capacity in the U.S.

Based on a review of the various export figures, we project that under the HRD scenario natural gas exports will be somewhat above the NEB forecasts, but not higher than 51 x 10^6 m^3/y. The following rationale is used:

1. The total of the increase in natural gas exports, currently before the NEB in 1988-1989, is 15 x 10^9 m^3/y for the eastern U.S. market and 21 x 10^9 m^3/y for the California market. Added to the 27 x 10^9 m^3/y of existing exports this would come to 63 x 10^9 m^3/y maximum.

2. In 1988, Canada's total conventional natural gas reserves were 2080 x 10^9 m^3 and frontier reserves were 1047 x 10^9 m^3. Assuming a growth in Canadian domestic consumption of 2 percent per year from 46 x 10^9 m^3/y in 1987 to 68 x 10^9 m^3/y in 2007, and exports to the U.S. at a level of 50 x 10^9 m^3/y , to maintain the current reserve to production ratio of 20 to 25, we would need reserve additions of about 110 x 10^9 m^3/y. Analysis of reserve additions of marketable natural

Table 10. NATURAL GAS EXPORT FORECASTS, 10^9 m^3/y (HRD)

YEAR	GRI	CERI	NEB	ARC	LOBBE
1990	28.3	39.7	35.2	56.7	33.3
1995	34.0	51.0	40.0	62.0	43.0
2000	59.0	51.0	40.0	57.0	46.5
2005	56.7	-	39.0	48.2	51.0

> gas during the last 20 years shows, on average, reserve additions of about 130 x 10^9 m^3/y. Since future reserve additions are likely to be less than reserve additions in the past, we suggest that exports can not significantly exceed 50 x 10^9 m^3/y. However, if a decision were made to allow the reserve to production ratio to decline to 15 (similar to the U.S. level), the required reserves addition would be about 80 x 10^9 m^3/y and exports could be increased in proportion to the gas reserves added above the required minimum.

In summary, under the HRD scenario, Canadian gas producers will experience a consistent level of demand and higher wellhead prices will provide a good resource investment environment. With natural gas supply and demand in balance, as world oil prices increase, natural gas will follow oil prices up and increase somewhat relative to oil, but to a lesser extent than under the HOI scenario. In addition, with prices of $5.00/GJ at the wellhead, large volumes of frontier resources and significant quantities of low permeable resources in Canada's conventional areas become economic (Bowers and Kutney, 1987). Therefore, under the HRD scenario, increases in natural gas prices will be limited by significant increases in the availability of gas in Canada and the United States.

4.3.3. Frontier and Synthetic Crude Developments

A combination of increases in world oil prices, declining production from conventional reserves in western Canada, and an increase in Canadian domestic crude oil consumption due to higher GDP growth would allow for the development of frontier reserves and synthetic crude plants to meet the demand. When compared to the HOI scenario, oil prices in the HRD scenario are high enough to replace oil imports with Canadian production from offshore and Arctic reserves, and increased synthetic fuel production from bitumen and heavy oil. The import of light crude oil would remain at a level of about 20 Mm^3/d, during the scenario time-frame, i.e. at about 1/5 of the HOI scenario imports by the year 2007.

The HRD scenario crude oil price of $35/bbl by the year 2007 exceeds expected production costs from the Nova Scotia offshore ($19/bbl to $32/bbl), the MacKenzie Delta and Beaufort Sea areas ($23/bbl to $25/bbl), and the cost of synthetic crude from new tar sands plants ($27/bbl to $36/bbl) (see Vol. 2, Chapter 1).

Production from new light crude oil sources would have to be 26 Mm^3/d in 1997 and 66 Mm^3/d by 2007. The frontier reserves are estimated at 29.9 x 10^6 m^3 for the Nova Scotia offshore and 253.2 x 10^6 m^3 for the MacKenzie Delta and Beaufort Sea areas (Vol 2. Chapter 1). Under optimal conditions, the eastern offshore production is estimated at 25 Mm^3/d (NEB, 1988). For the MacKenzie-Beaufort area, the maximum production is estimated at 24 Mm^3/d, which would require construction of a pipeline linking the reserves with Alberta pools. This would still leave a shortfall of 17 Mm^3/d in 2007 which would have to be supplied from the western sedimentary basin at levels above the projections for the HOI Scenario. It could include additional small pools or production from enhanced recovery from the existing pools. Such a target may, however, be difficult to achieve according to AERCB projections which estimate additional production capacity, in a high oil price scenario, at not greater than 10 to 12 Mm^3/d (AERCB, 1988).

Under the high oil price scenario, heavy oil and bitumen upgrading would become an attractive source of light crude oil. The HRD scenario projects synthetic crude production of 62 Mm^3/d in 1987 and 74 Mm^3/d in 2007, from 29 Mm^3/d in 1987 (Table 11). This would require the following synthetic crude capacity additions during the scenario:

1. Co-op Upgrader at capacity of 8 Mm^3/d before 1990 for processing heavy oil.
2. Construction of Bi-Provincial Upgrader at 7 Mm^3/d capacity and further increases in Syncrude's and Suncor's capacity by a combined 6 Mm^3/d before 1997.
3. An additional upgrading plant of 12 Mm^3/d before 1997.
4. A second additional upgrading plant or expansion of existing capacity by 12 Mm^3/d before 2007.

The above requirements may be too optimistic in terms of the industry's capability and willingness to undertake heavy investments in synthetic crude plants. It reflects high world oil prices sustained over a long period of time. It may require government commitments to secure steady oil supplies. However, the alternative of importing over 100 Mm^3/d of crude at $35/bbl would be unacceptable to any level of government given Canada's resource potential.

Table 11. SUPPLY AND DISPOSITION OF LIGHT CRUDE OIL Mm^3/d (HRD)

	1987	1997	2007
PRODUCTION CAPACITY			
Conventional[1]	195	186	196
Synthetic[2]	29	62	74
SUBTOTAL	224	248	270
DOMESTIC SUPPLY[3]	186	206	224
TOTAL DOMESTIC REQUIREMENT[4]	212.9	230	246
NET IMPORT REQUIREMENT[5]	27	24	22

[1] based on NEB (1988) data

[2] as for HOI Scenario plus two 12 Mm^3/d plants (in 1996 and 2000)

[3] at 83% of production capacity

[4] includes producers consumption (7.5%)

[5] does not consider alternative fuels

In addition to crude oil production from offshore and Arctic reserves, synthetic crude from bitumen and heavy oil, this scenario would require a limited use of NGL's as transportation fuel. Under favorable conditions, NGL's could replace up to 20 Mm^3/d of imports (CPA, 1988). Thus, under the HRD scenario, Canadian imports of light crude oil could almost be eliminated, while Canada would continue to be a net exporter of heavy oil.

4.3.4. Efficiencies in Existing End-Use Applications

Improvements in efficiency, above that of HOI Scenario, will result from the higher costs of energy. The increase in efficiency will not be as large as that observed during the 1970's and early 1980's. Given the high energy prices for this scenario, there will still be significant scope for energy savings in residential and commercial buildings (appliances, lighting, insulation levels, heating and cooling systems) and in industry where new process and technology will emerge with savings of 1/3 to 1/2 on energy consumption obtainable. However, in the HRD scenario the focus of the economy is on significant investments by industry in more primary energy production rather than on the development and supply of highly efficient fuel-saving equipment.

It is projected that under this scenario, the improvements in energy efficiencies and conservation efforts due to high energy prices will be basically offset by the robust nature of the economy. As such, the domestic consumption of crude oil under the HRD scenario is 246 x 10^6 m^3/d vs 252 x 10^6 m^3/d under the HOI scenario. In addition, although gasoline prices are projected to be 1/3 higher by the year 2007 under the HRD scenario vs the HOI scenario, the consumption of gasoline will be the same. Domestic consumption of natural gas is projected to follow only a slightly different pattern than oil with consumption reaching 90 x 10^9 m^3/y in 2007 under the HRD scenario vs 86.5 x 10^9 m^3/y under the HOI scenario.

4.3.5. Fuel Interchangeabilities

Under the HRD scenario, oil and gas prices are moving up relatively in tandem and their interchangeability in the conventional thermal markets will not be altered significantly. Both oil and gas will, however, come under increasing competition from electricity and coal.

The use of electrical energy in Canada does not follow world oil prices because most of the Canadian utilities are not reliant on oil-based generation. In addition, new technologies and new types of service industries will favor the use of electricity over oil and natural gas. As such, electricity as a percentage of total energy consumption in Canada, will increase during the scenario time-frame. Further, the use of coal-fired generating facilities will increase in the absence of any increased concern over greenhouse gas effects. Technical advances will allow cleaner burning of coal without uneconomic costs for SO_2, NO_x, fly ash and particulate clean-up, i.e., coal use could reappear in some large industrial applications.

The use of nuclear power will not increase in Canada under the HRD scenario because of the ready availability of alternate sources of energy and a continuing negative public perception with respect to the risks of nuclear accidents, the problems of waste disposal and the dismantling of reactors after their service life is over.

The impetus for fuel interchangeability in the transportation sector under the HRD scenario will be similar to that for the HOI scenario, i.e., primarily due to government regulations on vehicle efficiencies and emission controls.

4.3.6. Environmental Concerns

Environmental concerns and government policies will be similar to those for the HOI Scenario. The key issues are going to be acid rain, carbon dioxide build-up, ozone layer depletion, waste disposal, water quality and land management. The concerns are going to be significant but not great enough to prevent heavy resource development or to require implementation of high cost environmental measures.

Natural gas will continue to be the preferred hydrocarbon fuel, but in the early 2000's the cost differences between natural gas, oil and coal will be large enough to see increased use of coal along with increased environmental protection controls.

With respect to transportation fuels, similar to the HOI scenario, stricter regulations are expected for gasoline CO emissions during the winter and for diesel emissions in urban areas. The scenario includes increasing oxygenate levels in gasoline to 2 percent of oxygen and the use of alternate fuels in place of diesel fuel, at a level equal to 10 percent of the diesel consumption in 2007 on an energy equivalent basis. A 10 percent tax is also factored into the projected diesel prices beginning in 1997.

4.3.7. Government Involvement in the Economy

Given the scenario outline of a very strong Canadian economy, a more open international marketplace and a good investment climate for Canadian industries, the various levels of government would be expected to continue the movement towards deregulation, privatization and allowing market forces to prevail.

In the first decade of the HRD scenario, because of the hang-over of large budget deficits, government involvement in the stimulation of energy development would be limited. However, in the second decade, with a very healthy and active resource sector and increased tax revenues, governments could take a more active interest in fostering enhanced oil and gas recovery, offshore and Arctic developments and in ensuring that environmental issues are considered by the energy sector. As much as government policies are expected to be restricted to incentives and measures aimed at minimizing pollution before the year 2000, after that, the government may again undertake an active participation in the development of primary energy resources and technology. In particular, large developments of synthetic crude plants for bitumen would require stable high oil prices over a long period of time.

Under the HRD scenario it is expected that significant R&D efforts would be undertaken by the energy industry in primary production, i.e. improved techniques for enhanced oil and gas recovery from conventional areas, and in the development of environmentally acceptable techniques for developing frontier resources cost effectively. Government policies would support industry efforts.

4.3.8. Structural Changes and Key Issues

Because the scenario is characterized by high energy resource development in frontier oil and bitumen upgrading, significant structural changes can be expected in the energy industry and the Canadian economy.

The economy of western provinces would be expected to play a leading role in the national growth; however, the economic activities and infrastructure development would be somewhat different from those that different from those that took plac
Most of the oil exploration activities and bitumen development would be concentrated within fewer areas and would be expected to require less infrastructure.

The profile of the oil industry would likely be changed. Frontier and synthetic crude developments require massive capital, large organizational capabilities and economies of scale. Enhanced oil recovery techniques require significant R&D efforts which are very costly. Smaller and medium size oil companies may find themselves left on the outside or would be integrated with larger companies. The oil and gas industry could be expected to become more oriented towards technological and organizational factors, rather than towards finance and taxation issues such as in the early 1980's.

The key issues in the HRD Scenario are:

- strong world oil prices allowing increased oil and gas prices in Canada
- a strong Canadian economy and a healthy open world economy

- government and industry emphasis on primary energy development rather than on conservation and end-use efficiency.
- development of frontier oil and gas resources as well as bitumen and heavy oil deposits and increased emphasis on enhanced recovery techniques in conventional areas.
- increased competitiveness of coal and electricity
- markets for gasoline enhancers and extenders similar to the HOI scenario
- environmental regulations similar to the HOI scenario.

4.3.9. High Resource Development Scenario Results

Tables 11 and 12 depict the projected supply and disposition of light crude oil for the period 1987-2007 and the projected consumption of transportation fuels in Canada. The assumptions that support this scenario include high economic growth, high world oil prices, increasing natural gas prices and no significant changes in energy consumption patterns with the exception of government legislation concerning gasoline and diesel emissions.

The most significant feature from the tables is that the net oil import requirements remain below the 1987 level of 27 Mm^3/d, conventional production capacity remains at the 1987 level of about 190 Mm^3/d, and synthetic crude production increases from 27 Mm^3/d in 1987 to 74 Mm^3/d in 2007. As such Canada will continue to be a net importer, albeit small, of light and medium crude oil.

Table 12. CONSUMPTION OF LIGHT CRUDE OIL OR TRANSPORTATION FUELS, Mm^3/d (HRD)

TRANSPORTATION SECTOR	126.5	135	144
Gasoline	90.0	94	98
Middle Distillates	42.7	48	53
HFO	2.6	3	3
TOTAL Canadian[1]	197.0	213	228

[1] excludes consumption (7.5%)

It is expected that there will continue to be a limited capacity in Canada to refine heavy crude oil into gasoline and light fuel oils. Where the opportunities are taken to upgrade and refine synthetic derived fuels, these fuels would have characteristics unique to Canada and may affect the performances of vehicles using the fuels.

The natural gas prices in this scenario are projected to rise from a fieldgate price of $1.70/GJ in 1987 to $5.00/GJ in 2007 (Table 13). This price increase reflects the replacement cost of current production with natural gas from the MacKenzie Delta and the Beaufort Sea areas in the late 1990's and offshore eastern reserves in the early 2000's. The rise in natural gas prices is possible due to increased world oil prices and a steady demand in the U.S. for Canadian exports.

Natural gas will continue to be used as a premium fuel although its competitive advantage vs electricity and coal would be somewhat eroded (Tables 14 and 15). By the year 2007, natural gas prices would be on par with crude oil prices and would increase by 8 percent relative to electricity in central Canada and 16 percent (relative) in western Canada (Table 14).

It is expected that the projected price difference between coal and natural gas will be large enough in the year 2007 to justify additional environmental controls for coal. For example,

Table 13. NATURAL GAS PRODUCTION, EXPORTS AND PRICES (HRD)

	1987	1997	2007
PRODUCTION[1], 10^9 m^3/Y	89.9	132	141
EXPORT[2] 10^9 m^3/Y	27.7	46.5	51.0
PRICES, $/GJ			
Fieldgate[3]	1.70	3.00	5.00
Toronto[4]	2.95	4.10	5.75

[1] Statistics Canada (1987), NEB (1988) data for domestic demand for year 1997/2007 plus export

[2] Addition of ANR, PGT, and Home Oil pipelines to export markets ($.3 + 7.3 + 7.2 10^9 m^3/y)

[3] NEB (1988) projection for 1997 and 2007; 1987 Alberta gas price CPA (1988)

[4] industrial users (vs 2007 oil price $.93/GJ); 1987 price is an average industrial service in Toronto

Table 14. COMPARISON OF ELECTRICITY AND NATURAL GAS PRICES[1], $/GJ (HRD)

	1987		2007	
	Ind.	Comm	Ind.	Comm
Electricity[1]				
Western Canada	10.70	12.65	15.90[3]	-
Central Canada	11.90	13.35	17.68[3]	-
Natural Gas[2]				
Western Canada	1.82	3.87	5.35	-
Central Canada	3.34	4.69	6.50	-

[1] Energy Pricing News, vol. 7. No. 7, July 28, 1987

[2] Energy Pricing News, vol. 7, No. 8, August 11, 1987

[3] escalated at 2 percent real per year

Table 15. COMPARISON OF ENERGY PRICES AND ENVIRONMENTAL COST FOR DIFFERENT FUELS, $/GJ (HRD)

	1987		1997		2007	
	W. Can.	Ont.	W. Can.	Ont.	W. Can.	Ont.
Natural Gas	1.82	3.34	3.87	4.69	5.35	6.50
Coal[1]	1.93	2.06	2.21	2.77	2.63	3.72
HFO	-	4.60	-	6.19	-	7.75
Coal with Environmental Controls[2]	2.16	2.58	2.51	3.46	3.03	4.65

[1] Coal prices escalated at 3 percent per year (real), includes $1.00/GJ transportation and handling charge for western Canada.

[2] estimated at 25 percent of cost of energy

in western Canada in 1987, coal prices (f.o.b. plant) were, on average, six percent higher than natural gas, on an energy equivalent basis. In 1997, coal prices are projected to be only 65 percent of natural gas, after the costs of environmental controls are incorporated. By 2007, coal prices are projected to be less than half of natural gas prices (Table 15).

The utilization of natural gas as a source of hydrogen for heavy oil and bitumen upgrading is estimated at 3 to 4 x 10^9 m^3/y by the year 2007. This is too small to affect natural gas pricing or its availability for other uses.

Similar to the HOI scenario, environmental pressures will create a window of opportunity for natural gas based chemicals that can be used as gasoline additives and blends (Table 16). As was the case in the HOI scenario, methanol fuel prices would be attractive in the mid-1990's on an energy equivalent basis. However, unlike the HOI scenario, the oil companies are in a much stronger financial position in the HRD scenario to choose to invest capital into refining capabilities to make higher octane components from oil instead of choosing to use natural gas based oxygenates as enhancers and extenders.

Under the HRD scenario, considerable investments will be made in Canada in the development of heavy oil deposits and synthetic crude production from bitumen deposits. However,

Table 16. POTENTIAL FOR ALTERNATIVE FUELS (HRD)

	1987	1997	2007
FUEL PRICES			
Crude Oil $/bbl	20.00	26.50	35.00
Gasoline, ¢/L	35	43	53
Diesel, ¢/L	30	37	46
MINIMUM POTENTIAL[1]			
Gasoline, PJ/Y	0.4	12	25
Diesel, PJ/Y	-	19	43
Methanol Equivalent, kt/Y	19.6	1,550	3,400

[1] 2% of oxygen in gasoline over 6 winter months by 2007
10% energy equivalent diesel fuel replacement by 2007

Canada will continue to import light crude oils rather than upgrade refining capacity to handle more heavy and synthetic crude oil. The reason is one of economics - it will be cheaper to import the light crude and/or refined petroleum products from the Middle East and third world countries.

The effect on the Canadian petrochemical industry will be interesting. Because the price of natural gas in this scenario does not rise relative to oil as much as in the HOI scenario, there is less of a squeeze on Canadian producers from countries using imported oil as feedstocks for petrochemical production (Table 17).

However, Canadian producers are faced with rising gas prices that are based on replacement costs from frontier areas. The competition from the Middle East countries will be formidable because of the secure feedstocks in those areas at costs that do not have to escalate appreciably during this time-frame. In addition, Middle East producers will be able to deliver petrochemicals into North American markets on a much more competitive basis because the transportation component of the delivered cost will become less of a factor as petrochemical prices rise along with world oil prices.

Table 17. PROJECTED PRICES FOR SELECTED PETROCHEMICALS (HRD)

	1987	1997	2007
METHANOL, ¢/L	22.6	28	35
ETHYLENE, $/tonne	381	491	649
METHANOL (fuel)[3], ¢/L	16.3	25	39
BENZENE, $/tonne	386	460	557

Thus, although the markets for petrochemicals will be strong in the HRD scenario because of a robust world economy, Canadian petrochemical producers will face a more difficult competitive environment than under the HOI scenario.

The opportunities for the natural gas conversion to fuels and fuel components in the HRD scenario are as follows:

- application of MTBE and oxygenates as gasoline additives to increase gasoline octane rating and reduce emissions from gasoline engines.
- conversion of natural gas to methanol, ethane, etc., to reduce the transportation cost component in the exploitation of remote natural gas resources.
- use of CNG and natural gas based fuels to reduce the cost and/or emissions of particulates and other pollutants from fleet vehicles and transit buses.

The constraints on the increased use of natural gas for conversion to alternate fuels in the HRD scenario are as follows:

- the natural gas industry will see good returns on gas sold into conventional thermal markets.
- the increase in value through secondary processing necessary to justify new petrochemical plants in Canada may not be available beyond the mid to late 1990's.
- oil refiners in Canada may find it more attractive to invest in modifications or additions to their refineries, either for financial reasons or control over inputs to the final refined products, rather than utilize natural gas based additives.
- Canadian petrochemical producers will face a more difficult competitive environment than under the HOI scenario.

4.4. High Vehicle Efficiency Scenario (HVE)

This scenario was chosen to represent a significant increase in environmental concerns, energy conservation and efficiency measures against a backdrop of low economic growth and low world oil prices.

4.4.1. Economic Parameters

In the High Vehicle Efficiency (HVE) scenario, Canada's economic growth will average 2 percent per year over the time-frame of 1987 to 2007. It is assumed that trade imbalances, government deficits, low world economic growth, third world debt problems and high real interest rates will result in low demand and low prices for crude oil in the world markets. Oil prices are expected in the range of $20 - $24/bbl ($Cdn, 1987) over the scenario time-frame.

A major difference between the HVE and the HOI scenarios is an increase in society's environmental awareness compelling governments to impose a number of regulations aimed at reducing greenhouse gas emissions, reducing acid rain emissions, and protecting water and land resources.

Under the HVE scenario, governments have to balance high deficits, while dealing with high unemployment levels and high inflation. With low cost off-shore oil available, governments will view primary energy development as a low priority issue and the investment climate for the energy sector in Canada will be weak. Therefore, the production and supply of Canadian light crude oil will follow the projections developed in the HOI scenario.

4.4.2. Availability and Price of Natural Gas

As in the HOI scenario, the availability of natural gas will not be a constraint in this scenario. However, prices for natural gas will rise faster than in the HOI scenario because of the environmental attractiveness of natural gas as compared to other fuels.

The natural gas prices in this scenario will rise from a fieldgate price of $1.70/GJ in 1987 to $2.20/GJ in 1997 and to $3.85/GJ in 2007 ($CDN, 1987). This represents a 10% increase over the prices projected for the HOI scenario.

The total volumes of natural gas for domestic and export purposes again follow the projections developed for the HOI scenario. Because of increased efficiencies in energy utilization, domestic consumption will not be higher. Further, the substitutability of natural gas for oil is limited in the Canadian industrial market. In the U.S. market, there is a greater degree of substitutability of gas for oil, and gas for the industrial market will allow for a stronger export price.

As a result of slightly higher prices in the U.S. market, increased production in the U.S. will preclude any significant increases in Canadian exports to that market. In addition, there may be some pressure on governments in Canada to limit any growth in exports of gas because of its desirability as a preferred "clean" fuel in Canada.

Table 18 summarizes the availability and prices for natural gas and light crude oil in the HVE scenario.

4.4.3. Efficiencies in Existing End Use Applications

Improvements in efficiencies for economic reasons will be low, similar to the HOI scenario. However, an emphasis on the reduction of carbon dioxide emissions through increases in the efficiency of fossil fuel use will be the key initiative by governments under this scenario. Other options to reduce carbon dioxide emissions will be alternative non-petroleum fuels, renewable energy technologies, and preferential use of those fuels which yield less carbon dioxide per unit of energy used. However, given the HVE scenario of low oil prices and a relatively weak economy, a movement to non-petroleum fuels or renewable energy technologies would be very limited because of the high cost (real and perceived) of these alternatives. This would leave increased efficiencies and low carbon dioxide emissions fuels as the only viable approaches.

Table 18. ENERGY SUPPLY AND PRICING (HVE)

	1987	1997	2007
NATURAL GAS			
Domestic Supply, $10^9 m^3$/y	89.9	122	133
Export, $10^9 m^3$/y	27.7	47	47
Prices[1], $/GJ			
Fieldgate	1.70	2.20	3.85
Toronto	2.95	4.20	4.70
LIGHT CRUDE OIL			
Domestic Supply, $10^3 m^3$/d	186	174	149
Prices[1]			
Crude, $/bbl	20.00	21.91	24.00
Gasoline, ¢/L	35	41	44
Diesel, ¢/L	30	39	42

[1] 10% above HOI Scenario

Petroleum based transportation fuels are significant contributors to carbon dioxide emissions. When the production and distribution aspects of petroleum based transportation fuels are included, in 1987 the use of highway fuels accounted for approximately 27.6 percent of Canadian fossil fuel carbon dioxide emissions (Appendix F). For transportation fuels, a reduction in carbon dioxide emissions could be best effected by increasing the efficiency of motor vehicles and through tax measures on "gas guzzlers". The current laws in the U.S. require automobile manufacturers to achieve an average efficiency of above 26 mpg (9.05 litres per 100 kilometres) for new vehicles. This requirement would have to be increased to above 48 mpg (4.90 litres per 100 kilometres) by the year 2007, if a target reduction of 20 percent in carbon dioxide emissions was to be met.

In the industrial and commercial sectors, technological options are available to increase the efficiency of energy use. Canada spends 8 to 10 percent of its GDP on energy use which is much higher than, for example, what Japan spends on energy (6 percent). Even considering the structural differences between the two economies, there is potential for further increases in energy efficiency in Canada.

According to the Brundtland Report, the energy consumption per output from the most efficient processes and technologies is one-third to less than one-half of typically available equipment.

In an industrial country such as Canada, as much as a 20 to 30 percent increase in energy efficiency could therefore be achieved.

The economic benefits of such improvements would be quite substantial, in addition to the environmental benefits. For example, a 25 percent improvement in energy efficiency across all energy use sectors in Canada would be equivalent to adding over 10 billion dollars to the GDP.

4.4.4. Fuel Interchangeabilities

Under the HVE scenario, alternate lower carbon dioxide emission fuels would be utilized wherever they represent an economic substitute or even a substitute at a slight premium in price. However, the choices during the time-frame of the HVE scenario are likely to be limited to nuclear power, electricity generated by hydro-power and batteries, fuel cells, hydrogen and possibly photo-voltaics.

The potential for energy from geothermal sources, biological production of liquid fuels, active solar, wind generated power, etc., is viewed as limited because of governments' limited financial resources to encourage a broad range of alternative energy technologies.

Nuclear power is not considered to be an option for Canada in this scenario given the negative public perception of nuclear power. Even in the event of significant public concern over carbon dioxide build-up in the atmosphere, nuclear power would be viewed as a less favored option.

Electricity generated by hydro would be the preferred option where available, although there is a finite amount of potential for hydro electricity in this country. The situation could develop under this scenario whereby the increased demand for electricity in Canada will have to be met either by expensive clean coal combustion plants or nuclear energy, while significant amounts of "clean" hydro electricity is being exported to the United States. Again, there is a need to look at the full cycle to determine the net impact of hydro electric power on the environment.

Natural gas emits about 1/2 less carbon dioxide than coal and about 1/3 less than oil on an energy equivalent basis. Given the relative economics of the three fuels in this scenario, natural gas would be used to reduce greenhouse gas emission. However, in spite of the severe pressure on the use of coal and heavy fuel oil in the industrial sector in this scenario, we do not foresee a major substitution of these fuels in the Canadian market sectors because they are not readily interchangeable (see Volume 2 Section 3).

Alternates to petroleum based fuels under this scenario would include methanol fuels, ethanol fuels, CNG and propane. Diesel fuels will be less environmentally acceptable than under the HOI scenario.

4.4.5. Environmental Concerns

A significant increase in environmental awareness and regulations is projected under this scenario. The global "greenhouse" effect and local and regional air quality issues will become number one priorities for the government.

The effects of global warming on agriculture, forestry and a potential increase in extreme weather activities will be major concerns. Events that start the scenario and bring about these concerns are as follows:

1. Scientists' predictions of the man-made effects on the atmosphere are confirmed by the discovery of a stratospheric ozone hole over Antarctica. The impact of this discovery is particularly strong since many scientists agreed that chlorofluorocarbons may damage the stratosphere ozone but no one expected such a sudden effect.
2. Measurements of greenhouse gases concentration in the atmosphere point to a steady increase of carbon dioxide and other greenhouse gases beyond historical fluctuations, as shown by the evidence presented by earth geology.
3. Better understanding of the interrelation between the atmosphere, land forestation and ocean currents lead to more precise capabilities in determining climate trends and its consequences on global habitat. Results point to an accelerating global warming which, in the best case, could only be slowed down, but not reversed, in the next two decades.

4. Rapid deforestation in Brazil and other third world countries brings additional concerns about the compounding effects of man's activities on the climatic changes.

As a result of public pressure, a number of government and international initiatives have taken place on the greenhouse gases issues. Major international initiatives include the signing of an international accord on phasing-out the production of chlorofluorocarbons and establishing a target goal for carbon dioxide emissions reduction of 20 percent by the year 2007 (Montreal Accord, 1989). The HVE scenario includes, therefore, a 10 percent reduction of carbon dioxide emissions by 1997 and a 20 percent reduction by the year 2007, based on 1987 emission levels.

In addition, strict source emission standards for utilities and industrial boilers and furnaces are also projected under this scenario. Canadian standards would approach those in the EEC and Japan by the early 1990's and would apply not only to new power plants but, with some flexibility for trading of allowable emissions, also for existing coal burning plants (Table 19). These measures would add significantly to the price of electricity, especially in western Canada.

Canada's approach to reduced diesel fuel emissions in this scenario would be based on current California legislation: 1) strict control on diesel emissions outside urban areas; and 2)

Table 19. SOURCE EMISSION STANDARDS FOR UTILITY BOILERS (>100 MW, 1987) (HVE)

	CANADA	U.S.	EEC	CANADA FUTURE
SULPHUR DIOXIDE, ng/J	258	516	129	129
NITROGEN OXIDES, ng/J	258	--[1]	210	65[2]
PARTICULATES, ng/J	43	13	32	32

[1] approx. 60 percent removal required

[2] EEC scheduled after 1995

Sources: Weiler et al. (1988)
Environment Canada (1985)

conversion of diesel trucks and buses in urban areas to alternative fuels by the year 2000. The targets would be somewhat relaxed in comparison to the Los Angeles standards where consumption of liquid petroleum fuels is projected to be reduced by 30 percent by the year 2000.

The fuels and technologies available for the replacement of diesel trucks or buses in urban areas are methanol, CNG, or electric fleet vehicles. The approaches available for reduction of diesel emissions outside urban areas may include the application of new emission control technologies, and the substitution of diesel with gasoline engines.

The scenario also projects a reduction in evaporative hydrocarbon emissions from vehicles by reductions in gasoline Reid Vapor Pressure (RVP) and improvements in on-board emission control canisters for vehicles. New regulations would require a reduction of RVP during the summer months to less than 11.5 psi, by 1997. No change is envisaged for winter RVP standards currently at about 13.5 psi. The RVP regulations would preclude the use of methanol or other alcohols as gasoline blending components during the summer. However, other gasoline components such as MTBE could be used to achieve reduction of carbon monoxide emission throughout the year.

As a result of growing environmental concerns and government legislative action, this scenario envisions more strict regulations on gasoline CO emissions during winter time and for diesel emissions in urban areas. The scenario incorporates a provision for increasing oxygen levels in gasoline to 2 percent in oxygen to reduce CO emissions in winter time, and for the use of CNG and/or alcohols in place of diesel fuel, at a level equal to 10 percent of the diesel consumption in 2007 on an energy equivalent basis. A 10 percent tax is also factored into the projected diesel prices, starting in 1997. This tax is implemented to offset the tax loss from alternative fuels.

A reduction of RVP by 2 to 3 psi may require removal of butane from the base gasoline. This could have a significant effect on natural gas processing plants and on refineries operations, with a possible result of a surplus of butane in the market and reduction of the butane revenues to the gas producers. A more detailed discussion of the butane surplus is given in the scenario results.

Increased environmental concerns would impose additional constraints on bitumen production and upgrading. Satisfactory resolution of issues such as water and land use, waste disposal and sulphur emissions from bitumen upgrading plants, would be required before additional bitumen mining and processing could take place. It is expected that any incremental technology gains in bitumen upgrading would be offset by the added cost of environmental regulations with the cost of synthetic crude remaining at the 1987 current level under this scenario. Also, because of the low world oil prices, no significant new synthetic crude developments are envisaged.

It is expected that environmental constraints on crude oil production from offshore and Arctic reserves would be more stringent, and, with low oil prices, no major development of these resources are expected under this scenario.

Exploitation of gas reserves from the Arctic and offshore regions will also require a compliance with stricter environmental regulations. Such regulations would add not only to the cost of the reserves development but also would extend the time required to obtain the necessary approvals for the production and the transportation of natural gas.

4.4.6. Government Involvement in the Economy

Because of large budget deficits, government fiscal involvement in the energy sector would be limited in the HVE scenario. However, government involvement would be high in formulating regulatory and environmental targets for all industry sectors.

Government initiatives would be required to promote environmental improvements while at the same time keeping government expenditures minimal. This would preclude spending more government money on environmental protection programs or on industrial assistance to implement new environmental technologies. Government's role would be to emphasize its regulatory powers such as setting up industry wide environmental goals and targets, and developing policies which would promote private sector initiatives to improve environmental quality in a manner that is effective and economical. For government policies to succeed, market forces would have to be directed to work together and in support of the environmental and social goals. However, industry and the general populace will not invest willingly in environmental matters unless they are educated as to the need. Thus an important role for the government will be to conduct information campaigns and to pursue efficiency in energy use in all public sector activities. Technology transfer and information dissemination will be key aspects of a limited budget initiative.

Under the HVE scenario, one of the major responsibility of government will be to encourage international agreements. However, governments would not able to implement significant new levels of taxation on the use of fossil fuels for two reasons: 1) the necessity to maintain the competitive position of Canadian industry in world markets; and 2) additional taxation on fossil fuels would not make a significant enough contribution towards meeting the target demand for carbon dioxide reduction. Some institutional practices and policies would have to change under the HVE scenario. This could entail a shift in the taxation of fuels, but, overall it would be government revenue neutral. In particular, fuel costing would have to begin to incorporate more of the social and environmental costs, governments would have to mandate efficiency standards on new vehicles, and new, more flexible practises to achieving environmental goals, such as trading of environmental permits, would have to be facilitated by regulatory bodies.

4.4.7. Structural Changes and Key Issues

A number of structural changes in the energy industry and in other sectors of economic activity would be expected under the HVE scenario.

The key issue in the HVE scenario is whether Canada will be able to meet the target reduction of 20 percent in carbon dioxide emissions by the year 2007 without setting off a severe recession in the economy. In other words, would Canada be able to make a transition from the current level of energy consumption to much more of an energy conservation and efficiency approach without slowing down its economy?

A second issue is the international co-operation which would be essential to achieve any meaningful global reduction in the atmospheric concentration of greenhouse gases. With an expected growth of 10 to 15 percent per year in energy consumption, developing countries will become major greenhouse gas contributors in the next century. The actions of Canada and other OEDC countries to cut down their contribution to global warming will not be sufficient on their own to reverse the global warming trend.

To achieve international co-operation, the industrialized countries would have to be sensitive to how the new policies are viewed by the third world. For example, the present emissions of carbon dioxide per capita are disproportionately large in developed countries, hence it will be difficult to persuade developing nations to apply any costly measures to increase energy efficiency.

The developed countries would therefore be expected not only to control their contributions to the greenhouse gases problem, but would also have to provide means for the developing countries to cut their emissions, while maintaining a reasonable economic growth. This could include technical and educational assistance to developing countries in areas of energy conservation, energy efficiency and alternative technology development.

A further issue is whether or not the reduction of carbon dioxide emissions by 20 percent would be effective in slowing down or reversing the global warming effect. Should it be that the 20 percent reduction would not prevent major global climate shifts, a number of structural changes aimed not only at prevention but also at adapting to the new environment would be required towards the end of this scenario time-frame.

A major shift should be expected in the Canadian energy industry. More environmentally acceptable fuels such as natural gas or electricity would command a premium demand while coal and heavy fuel oil would be less desirable. With low world oil prices, diminished investment would take place in synthetic crude or frontier oil development, and enhanced oil recovery. The natural gas industry will fare better but this will not be enough to create a positive investment climate in Canada's hydrocarbon sector. Few new energy development opportunities will occur with persistently low world oil prices.

The speed with which the different market sectors will reduce their consumption of crude oil will depend on the mix of energy used, the availability of substitute fuels or technology, the relationship between crude oil prices and finished product prices, and the nature and life-cycle of the energy equipment used.

It is expected that under the HVE scenario, the oil market would be characterized by an over-supply and natural gas markets would be reasonably balanced. The key issues in the scenario are, in summary, as follows:

- recognition of the sense of urgency and international co-operation on a concerted effort to control the build-up of greenhouse gases in the world's atmosphere.
- transition from energy consumption to energy conservation and efficiency through legislation and education.

- an absence of significant government expenditures on R&D efforts in the areas of new energy efficient technologies and renewable resources.
- implementation of policy and tax initiatives promoting energy efficiency, setting environmental goals and encouraging private sector initiatives to improve environmental quality.
- increased environmental constraints on the development of frontier oil and gas reserves and on bitumen mining and upgrading.
- increased environmental regulation on the use of diesel fuel.
- capability of automobile manufactures to increase an average new vehicle efficiency above 48 mpg (16.4 litres per 100 kilometres) by 2007.
- development of markets for gasoline extenders (methanol) and octane enhancers (MTBE).

4.4.8. High Vehicle Efficiency Scenario Results

The HVE scenario is based on low cost energy and the efficient use of energy. This would include reduction in light crude oil use and continuation of limited crude oil imports (Table 20). A number of policy measures are available to government under this scenario to help meet the environmental goals. Among those are fiscal policies such as allowing the retirement of capital stock faster, increasing mass transit development, collaborative investment in reforestation as part of the reduction of greenhouse gases, tax incentives to invest in energy conservation, other fossil fuels emission offsetting measures.

Table 20. CRUDE OIL SUPPLY AND DISPOSITION Mm^3/d (HVE)

	1987	1997	2007
DOMESTIC SUPPLY[1]	186	174	149
TOTAL DOMESTIC REQUIREMENT[2]	213	192	173
NET IMPORT REQUIREMENT	27	18	24

[1] See HOI Scenario

[2] reduced by 10% by 1997 and 20% by 2007

In the 1970's and 1980's, significant energy efficiency improvements were realized in all energy use sectors of the Canadian economy. This trend of significant energy efficiency improvements could not continue if world oil prices remain low. Therefore, to encourage further energy efficiency improvements in all sectors, mandatory energy efficiency standards on equipment, buildings, new vehicles, etc., would have to be considered by the government as policy options.

Most energy uses include some form of subsidies or do not reflect all of the social and environmental costs. Fuel pricing rarely includes the total costs of importing energy or the cost for damage done to health or the environment. Government energy policy incorporating the true cost of various fuels would further enhance the value of energy efficiency.

The emphasis on energy efficiency and a reduction in fossil fuel use does not necessarily imply stagnation for the energy industry or the Canadian economy as a whole. New technologies could be commercialized and more economic activities generated by marketing alternative technologies world wide. Japan has shown examples by through the development of advanced pollution control technologies for its use, first, and by marketing the new environmental technologies in Europe, North America, and Asia later.

However, given a commitment by Canada to significantly reduce its carbon dioxide emissions by the year 2007, the most immediate and effective measures are related to transportation fuels. Table 21 presents a summary of greenhouse gas emissions and costs for alternative transportation fuels and technologies. It is apparent from the table that to implement a significant reduction in carbon dioxide emissions only a handful of the alternatives can do the job. If the economic factor of low oil prices is also considered, the only suitable alternatives are: 1) increased vehicle fleet efficiency; and 2) increased use of CNG or NGL powered vehicles.

Table 22 depicts the target crude oil demand for the transportation sector under the HVE scenario. The amount consumed is projected at 127 Mm^3/d in 1987 and 102 Mm^3/d in 2007. Thus the amount of oil consumed in 2007 would be 20 percent lower than the 1987 oil consumption. Assuming that the majority of the reduction in oil consumption by the transportation sector would be accomplished through the increased efficiency of motor vehicles, the required improvement in the average vehicle efficiency, as compared to 1987, would be above 20 percent.

Table 23 depicts the current and projected all-vehicle efficiency required to meet the reduction in crude oil consumption. The average all-vehicle efficiency would be above 31 mpg (7.7 litres per 100 kilometres) by 1997 and 40 mpg by 2007

Table 21. SUMMARY OF GREENHOUSE GASES EMISSIONS AND COSTS FOR ALTERNATIVE TRANSPORTATION FUELS AND TECHNOLOGIES (HVE)

	PERCENT CHANGE PER MILE relative[1] to petroleum	BREAK EVEN COST ¢/L gasoline[2]
Hydrogen from Non-Fossil Electric	- 100	93
Electric Vehicles (EVs) from Non-Fossil Electric	- 100	64
CNG/LNG/Ethanol from Biomass	- 100	48[6]
2x Fleet Efficiency	- 50	n/a
CNG from Natural Gas	- 19	18-29[5]
NGL Vehicles	- 16	--
EVs from Natural Gas Power Plants	- 18	--
Methanol from Natural Gas (current technology)	- 3	28-52[4]
EV from Current Power Mix	- 1	--
Gasoline and Diesel from Crude	--	35-40
Gasoline and Diesel from Bitumen[3]	+ 42	43-55
Methanol from Coal (+30% eff. increase)	+ 51	--
EVs from New Coal Plants	+ 26	--
Hydrogen from Coal	+ 100	--

[1] in terms of carbon dioxide equivalent effects (see Appendix)

[2] for non-petroleum fuels prices indicated are 2/3 of the high range, for petroleum and natural gas derived fuels prices reflect scenario projections

[3] Lobbe Technologies Ltd. (1989)

[4] (1987)-(2007) price projections over the scenario period

[5] 1.8 times natural gas cost on energy equivalent basis

[6] Gaines and Flaim (1987)

Sources: DeLuchi et al., 1987
Lobbe Technologies Ltd.

Table 22. CRUDE OIL DEMAND FOR TRANSPORTATION SECTOR (HVE)

	1987	1997	2007
Projected Demand, Without CO_2 Reduction Mm^3/d	126.5	135	143
CO_2 Reduction Target, %	--	10	20
Crude Oil Demand Target, Mm^3/d	126.5	115	102
Amount of Crude Oil Reduced, Mm^3/d	--	20	41
Percent Required Reduction of Crude Oil Consumption	--	16	32

Table 23. CURRENT AND PROJECTED REQUIRED VEHICLE EFFICIENCY

	1987	1997	2007
RELATIVE INCREASE IN NUMBER OF NEW VEHICLES[1]	1	1.09	1.20
AVERAGE ALL VEHICLE EFFICIENCY REQUIRED, mpg	25	31[2]	40
ESTIMATED AVERAGE NEW VEHICLE EFFICIENCY	30	38-40[3]	48-50

[1] assumed number of cars per 1000 peoples stays at 453 (1986 data) population growth of 0.8 percent per year (Globe and Mail, 1989)

[2] 25 x 1.09 x 1.12

[3] assume about 6 mpg, 6 years efficiency lag between old and new fleet vehicles, see Figure 2 in "Fuel Substitutabilities in Different Market Sectors", vol. 2)

(5.8 litres per 100 kilometres). The new vehicle efficiency would have to increase to about 48-50 mpg (4.8 to 5.0 litres per 100 kilometres), which is probably the limit for current technology.

Taxation of transportation fuels, although relatively ineffective, would provide a further reduction in fuel use. However, in order to achieve a 20 percent reduction in fuel use through taxation, crude oil prices would have to be raised to the range of $50 - 60/bbl. This is not likely considering the low world oil prices and the low economic growth in the scenario. However, the revenue from taxation included in this scenario could be used to provide rebates towards purchases of higher efficiency vehicles.

Development of more public transportation is often cited as an effective measure to reduce the number of cars and hence transportation fuel demand. Statistics suggest that the effectiveness of this measure depends on many factors. For example, in West Germany, where public transportation is more developed than in Canada, by 1986 the number of cars per one thousand people was almost the same as the number of cars per one thousand people in Canada (Table 24). Similar trends are apparent in other OECD countries although they may still lag behind Canada and the United States. Statistics also show that the number of kilometers driven per person-day is much smaller in

Table 24. AUTOMOBILE DRIVING STATISTICS (HVE)

	KILOMETERS PER PERSON-DAY		CAR'S PER 1000 PEOPLE	
	1976	1986	1976	1986
CANADA	--	46	392	453
UNITED STATES	43	51	511	562
W. GERMANY	19	23	307	441
BRITAIN	17	21	260	325
JAPAN	6	9	162	237

Source: Globe and Mail (1989)

Japan and Europe than in Canada. This can be related to distances between cities, distances to work, disposable income and age distribution. One could infer that the number of kilometers per person-day in Canada will decrease in the future, but not fast enough to have a major effect on carbon dioxide emissions.

An interesting option is available for the conversion of natural gas under this scenario. Because of the more stringent reduction in RVP included in this scenario, it is suggested that butane will have to be removed from the base gasoline. This would result in a possible surplus of butane on the market and a reduction in butane revenues to natural gas producers.

MTBE is made from methanol and isobutylene which itself can be made from butane. MTBE blends have the advantage of being considered interchangeable with gasoline and they pose no additional evaporative emission problems while at the same time raising octane levels.

It is projected that MTBE demand in the U.S. could be nearly 10 million tonnes per year by 1995 and that domestic U.S. supply is unlikely to be much higher than 3 million tonnes by that date (Chem Systems International, 1989). Thus, an opportunity exists for conversion of natural gas to methanol and to MTBE based on: 1) sufficient Canadian supplies of natural gas feedstocks; 2) the availability of relatively low cost butanes; 3) a Canadian market that can justify a world scale plant; and 4) a large U.S. market that has insufficient domestic capacity to meet its requirements.

The price constraints on Canadian petrochemical producers will be similar to the HOI scenario, with the exception that some of third world producers that utilize low cost excess heavy oils as a feedstock, would provide additional pressures on Canadian producers. This could be counter balanced by the levy of appropriate duties.

The opportunities for the natural gas conversion to fuels and fuel components in the HVE scenario are as follows:

- use of MTBE and other natural gas based oxygenates as gasoline additives and as cleaner, less polluting fuels.
- use of CNG and natural gas based fuels in transit buses, fleet vehicles and truck freight to achieve reduction of carbon dioxide emissions while ensuring the required energy supply for these transportation sectors.
- use of highly efficient end-use technologies in the commercial, industrial and residential area.

The constraints on the increased use of natural gas for conversion to alternate fuels in the HVE scenario are as follows:

- significant quantities of low cost light crude oil available to Canadian refiners.
- lack of government funds to assist with the development of alternate fuels.

4.5. Non-Petroleum Fuels Scenario (NPF)

This scenario was chosen to describe the entry of non-petroleum fuels (NPF) in the transportation sector. The commercialization of NPF's would be possible due to a combination of the introduction of significant environmental protection measures by governments and high world oil prices.

4.5.1. Economic Parameters

The NPF scenario is characterized by economic parameters similar to the HRD scenario (i.e., high oil prices and strong GDP), however, the economic growth takes place in conjunction with stringent, global environmental protection measures which affect Canadian economic policies and directions.

In this scenario, world and Canadian economic growth is projected to increase at an average of 3 percent per year, and world oil prices, due to increases in demand, are projected to reach $35/bbl ($ Cdn, 1987) in 2007.

Similar to the HVE scenario, the environmental constraints will impose demands on the government which will have to be balanced against other national priorities such as economic development, inflation, unemployment, and increases in energy prices. However, unlike the HVE scenario, under the NPF scenario the government is in a much better financial position, and a vibrant Canadian economy will allow new directions to be chartered in energy development including the commercialization of non-petroleum fuels, an increased emphasis on energy efficiency, and the pricing of fuels at full social, environmental and production cost.

4.5.2. Availability and Price of Natural Gas

The availability and price of natural gas will be the same as outlined under the HRD scenario. Strong world energy prices will result in increased natural gas exploration activities. However, the total export and domestic demand will not increase substantially over the other scenario levels because of increased energy efficiency and conservation levels as well as increased U.S. domestic production in response to higher wellhead prices.

Table 25 summarizes the energy supply and pricing for natural gas and oil under the NPF scenario. World oil prices will increase to $26.50/bbl in 1997 and $35.00/bbl in 2007. At the same time, natural gas prices are projected to increase to $4.10/GJ in 1997 and $5.75/GJ in 2007.

Under the NPF scenario, Canadian gas producers will experience a consistent level of demand and higher wellhead prices will provide a good resource investment environment.

Table 25. ENERGY SUPPLY AND PRICING (NPF)

	1987	1997	2007
NATURAL GAS			
Domestic Supply, $10^9 m^3$/y	89.9	132	141
Export, $10^9 m^3$/y	27.7	46.5	51
Prices[1], $/GJ			
Fieldgate	1.70	3.00	5.00
Toronto	2.95	4.10	5.75
LIGHT CRUDE OIL			
Domestic Supply, $10^3 m^3$/d	186	206	224
Prices[1]			
Crude, $/bbl	20.00	26.50	35.00
Gasoline, ¢/L	35	52	64
Diesel, ¢/L	30	45	56

[1] 20% environmental tax on gasoline and diesel

4.5.3. Efficiencies in End-Use Applications

As was the case for the HVE scenario, an emphasis on the reduction of carbon dioxide emissions through increases in the efficiency of fossil fuel use will be a key initiative by governments.

However, this scenario includes a more concerted effort towards renewable energy development than was possible under the HVE scenario. The development of renewable energy sources will involve a significant commitment to energy efficiency actively promoted by government, not only through regulatory powers but also through the removal of subsidies on competing forms of energy.

Under the HRD scenario it was pointed out that technological options are available to the commercial and industrial sectors to significantly reduce energy consumption at the higher energy price levels. According to the Brundtland Report, most positive energy developments world-wide are economical with oil above $25/bbl. Thus, under the NPF scenario, higher energy prices will provide the incentive, and the economy will be strong enough for industrial and commercial customers to invest in new energy saving technologies.

The U.S. Environmental Protection Agency recently published a study which outlined steps that could be taken to mitigate the greenhouse effect (EPA, 1984). Two steps related to increased efficiencies; the amount of fuel used to heat a single family home could be reduced to 1/2 the amount used in 1980; and the average fuel consumption of all new automobiles should achieve over 40 mpg (6.9 L/100km). In the NPF scenario, emphasis will be placed on the fuel efficiency for vehicles because it is more readily attainable.

The reduction of crude oil consumption in the NPF scenario necessary to meet reduced carbon dioxide emission levels is similar to the reduction in the HVE scenario (42 Mm^3/d vs 40 Mm^3/d), hence, increased vehicle efficiency could account for the reduced crude oil consumption. However, the high world oil prices in this scenario make it possible for government to apply a mixed policy option by promoting high vehicle efficiency as well as the use of alternative, low carbon dioxide emission fuels. This policy would permit a growth in fuel use by the transportation sector beyond that which could be accommodated in the HVE Scenario through increased vehicle efficiency only.

Alternative fuels and technologies could provide an important economic activity for Canada, and allow the export of both petroleum and non-petroleum fuels and high efficiency technology abroad. It is likely that government and industry would respond to the opportunity to develop non-petroleum fuels and the technologies to use the new fuels and these opportunities would be pursued vigorously. It should be noted that under this scenario, Canada will continue to export coal, natural gas, oil and electricity.

4.5.4. Fuel Interchangeabilities

The choices for alternate fuels to reduce carbon dioxide are the same as for the HVE scenario: nuclear power, electricity generated by hydro-power, batteries, fuel cells, hydrogen, photovoltaics and CNG, propane, methanol and ethanol in transportation fuels.

However, given significant resources for R&D on the part of industry and the government, some of the more limited potential energy sources could be refined and adapted to more specific, smaller scale applications.

In addition, higher energy prices will allow a much broader scope for alternate fuels because of the greater economic flexibility for the alternatives, i.e. alcohols from wood, biological production of liquid fuels, geothermal energy, hot water and district heating systems based on the co-generation of heat and electricity, energy plantations, non-conventional hydro, etc.

The higher levels of world oil prices would also bring a number of conventional energy supply options within commercialization possibilities, (i.e., offshore oil, synthetic crude, enhanced oil and gas recovery projects), the details of which were described in the HRD Scenario. The key difference between the HRD and NPF scenarios, however, is that environmental constraints in the NPF scenario would place a ceiling on domestic market demand for fossil fuels and would penalize the use of fuels emitting pollutants such as CO_2. In effect, the total light crude consumption for transportation and other sectors would be reduced significantly enough, that a surplus of synthetic crude or frontier oil developed would be available for exports. A similar reduction in demand would be expected for other fossil fuels with the exception of natural gas which, as a premium fuel, could replace coal and petroleum. Natural gas emits about 1/2 the carbon dioxide compared to coal and 2/3 compared to oil, and it could be used in some areas to reduce greenhouse gas emissions. However, we expect that the environmental advantages of natural gas, on one hand, and the required increase in efficiency and reduction of fossil fuel use, on the other hand, would result in natural gas consumption being similar to that in the HRD scenario.

Table 26 short lists the fuels and technologies that would be available and capable of providing reductions in carbon dioxide emissions in relation to gasoline or diesel fuel during the time-frame under consideration. It is apparent from the table that with the price of gasoline at ¢64/L by the end of the scenario period (2007), a number of alternative fuels and

Table 26. SUMMARY OF COST AND GREENHOUSE GASES EMISSIONS FOR ALTERNATIVE FUELS AND VEHICLE TECHNOLOGIES (NPF)

	GG PERCENT CHANGE PER MILE relative to petroleum	BREAK EVEN COST ¢/L gasoline
Hydrogen from Non-Fossil Electric.	- 100	93
EVs from Non-Fossil Electric.	- 100	64
CNG/LNG/Methanol from Biomass	- 100	48
2x Fleet Efficiency	- 50	n/a
CNG from Natural Gas	- 19	18-36[1]
NGL Vehicles	- 16	--
EVs from Natural Gas Power Plants	- 18	--
Methanol from Natural Gas (current technology)	- 3	28-68
Gasoline and Diesel from Crude	--	35-64
Gasoline and Diesel from Bitumen	+ 42	43-55

[1] 1.8 natural gas cost on energy equivalent basis

Source: DeLuchi et al. (1987)
Lobbe Technologies Ltd.

technologies become economically viable for the transportation sector. Among the more interesting are electrical vehicles (EVs) from non-fossil electric fuel sources, CNG and propane vehicles, and transportation fuels from biomass.

Several issues will be key to the commercialization of non-petroleum fuels. These include:

1. Although some non-petroleum based fuels are already being used in Canada, widespread use will require the co-operation of fuel and vehicle manufacturers as well as several levels of government.
2. Fuels and technologies must be priced at their full social and economic cost.
3. Start-up barriers exist such as the possible requirement of a large network of new fueling outlets, high capital costs for new fueling stations, etc.
4. The swiftness of the transition away from petroleum fuels. In a situation with slow fuel penetration, fuels which can be used in blends such as methanol or MTBE or in multi-fuel combinations would have an advantage. In a rapid transition, the capability of gradual phasing in of new fuels would not be that important.
5. Vehicle manufacturers will have to build vehicles designed for and fully warranted for the non-petroleum based fuels.
6. The public's perception of future supply and prices will have to be similar for non-petroleum versus petroleum fuels.
7. A lot of R&D will have to be financed by both the government and the private sector.

4.5.5. Environmental Concerns

The environmental constraints and goals are the same as for the HVE scenario. The key concerns are:

1. The long-term effect of a build-up in greenhouse gases will be the prime environmental concern and a target will be set in Canada for a 10 percent reduction of carbon dioxide emissions for all energy sectors by 1997 and a 20 percent reduction by 2007.
2. Strict source emission standards will be adopted in Canada for full implementation by 2007. Details of the standards are shown in Table 19 in the HVE scenario.
3. A significant reduction of diesel fuel use will be required in urban and rural areas, with diesel trucks and buses in urban areas converted to alternative fuels by the year 2000.
4. Evaporative hydrocarbon emission standards will require a reduction of 2 psi in RVP for gasoline and improvements in on-board vehicle emission control canisters.
5. Increasing oxygen levels in gasoline to 2 percent in oxygen to reduce CO emissions in winter time, and the use of CNG and/or alcohols in place of diesel fuel, at a level equal to 10 percent of the diesel consumption in 2007 on an energy equivalent basis.
6. Much greater environmental constraints would be imposed on exploitation of bitumen and frontier reserves, with a result that cost gains realized by technological improvements would be offset by higher environmental costs.

4.5.6. Government Involvement in the Economy

Similar to the HVE scenario, strong environmental protection legislation will be implemented. Governments will set targets for industry-wide environmental objectives and enforce them. There are, however, important differences in the approach of government in the HVE and NPF scenarios.

In the HVE scenario, government chose to use standards for automobile manufacturers (i.e., mandated average new vehicle efficiencies) as a means of reducing greenhouse gas emissions. The taxation of transportation fuels was primarily to offset the costs of general environmental protection and any revenues lost from the use of oxygenated fuels such as methanol in place of gasoline. A significant increase in taxation of oil or petroleum products was ruled out because of low world oil prices and the need to keep Canadian industry competitive in international markets.

In the NPF scenario, because of higher world oil prices, governments can take a mixed policy approach, i.e. to legislate increased vehicle efficiency but also to encourage non-petroleum alternatives through taxation policies. In this scenario, a tax of 20 percent is applied on all petroleum products (50 percent total on refinery prices). It is significantly larger than for the other scenarios (30 percent on refinery prices for the HOI and HRD scenarios, 40 percent for the HVE scenario), but it would help to promote non-petroleum fuels in selected markets.

The revenues from the transportation fuels tax in this scenario would be in the order of 10 billion dollars per year. To put this in perspective, it should be noted that the federal spending on energy R&D in Canada was $44 million in 1979 and $170 million in 1984. Provincial government expenditures in 1985-86 were approximately $101 million. During the current period of fiscal restraint, the federal government is reducing its spending on energy R&D to $88 million and funding to demonstration projects that promote efficiencies and alternate energy techniques are also being reduced (EMR).

Under the NPF scenario the government would be in a position to provide fiscal incentives and to impose fees on the use of oil, coal and natural gas thus providing incentives to shift away from the use of fossil fuels. The government would also be in a position to allow innovative methods for the private financing of alternate energy projects, and technological improvements aimed at increased efficiencies and conservation.

However, the government would also have an important role to play in educating the general public as to the importance of conservation, the efficient uses of energy and the implications of unchecked environmental damage. The government would have to take a lead role in demonstrating its own dedication to efficiency in energy use, and to the use of alternate fuels on an economic basis. The government would also have to take a lead role in facilitating technology transfer and information dissemination, not only in Canada but in particular to third world countries.

4.5.7. Structural Changes and Key Issues

A number of significant changes can be expected to take place in all economic sectors. The NPF scenario offers opportunities of increased economic growth, new industrial activities, continued net exports of Canada's traditional forms of energy and a better environment for Canadian people.

The key issue is whether Canada and other world countries will be able to achieve the environmental and energy conservation goals envisioned under this scenario while maintaining a high GDP growth. A slowdown in the economy would shift the scenario to the HVE scenario. To help prevent such a shift, new environmental, alternate fuel and high technology energy utilization industries would have to provide a means for the Canadian economy to implement flexible and least-cost approaches to meet the environmental targets set by the government.

Under the NPF scenario, international cooperation would be essential, not only to achieve a reduction in greenhouse gases but also to maintain a high level of economic growth in developing countries. The challenges faced by developing countries would be much greater than the constraints imposed on developed countries like Canada. The NPF scenario will therefore require an unprecedented degree of economic and technical cooperation and assistance between the OECD and third world countries.

Major shifts could be expected in Canada's energy industries and manufacturing sectors. New technologies and processes would be commercialized and marketed abroad. Despite high environmental concerns, synthetic crude or fuels production would not be considered as sunset industries, but as new export industries for the U.S. and the Pacific Rim markets. This is in sharp contrast to the HVE scenario. Both crude oil and natural gas would be characterized by strong market demand.

The key issues in the NPF scenario are:

- maintaining strong economic growth while implementing a reduction of greenhouse gas emissions and more stringent general environmental controls across all energy sectors.
- transition from energy consumption to energy conservation and efficiency.
- provision of policy alternatives for energy development including commercialization of non-petroleum fuels, increasing energy efficiency and pricing of fuels at full social, environmental and production cost.
- development of flexible yet firm environmental goals for industry.
- technology development by industry of non-petroleum fuels, energy efficiency and environmental technology.
- a high degree of international cooperation in economic development and environmental protection.
- significant involvement of government in the economy through fiscal and regulatory avenues.

4.5.8. Non-Petroleum Fuels Scenario Results

Under the NPF scenario, natural gas and other fuels that minimize the generation of greenhouse gases during the entire production cycle will be favored. However, with relatively high energy prices, the availability of several alternate energy forms in particular renewable energy forms, and the effects of significant energy conservation efforts, there will not be a shortage of energy in the Canadian economy.

New generating facilities for the production of electricity from coal will be very limited and existing coal fired facilities will be required to meet stringent new emission regulations. There would be no additional nuclear power installations, due to the alternate energy options available and the prevalent attitude of the general population towards environmentally benign sources or energy.

Table 25 depicts the supply and prices for natural gas, crude oil and transportation fuels under the NPF scenario. The projected supply of natural gas increases from 89.9 x 10^9 m^3/y in 1987 to 141 x 10^9 m^3/y in 2007. As in the HRD scenario, concurrent with the increase in supply there is an increase in exports and natural gas prices.

One could suggest that the high environmental factors in the NPF scenario would result in a higher demand for natural gas than in the HRD scenario; however, we expect that increased efficiencies under the NPF scenario would offset the need for higher gas supplies and the export market would be met by higher U.S. domestic production. Natural gas production, exports and prices would, however, be higher than in the HVE scenario primarily due to higher economic growth and higher world oil prices.

The projected crude oil demand is the same under the NPF and HVE scenarios. In both cases 1987 crude oil demand was reduced by 10 percent in 1997 and 20 percent in 2007 (Table 27). The domestic supply of crude oil, under the NPF scenario, is assumed to respond to strong world oil prices and to reach levels similar to those projected in the HRD scenario. The combination of two factors - environmental concerns and high world oil prices - would result in Canada becoming a net exporter of light crude oil by the mid 1990's. Should non-petroleum fuels be rapidly commercialized under the NPF scenario, exports of light crude oil could be even larger than 54 Mm^3/d by the year 2007 (Table 28).

With significant investments in synthetic crude and alternative fuels developments the situation would be critical should high oil prices collapse. This suggests that the government's role under the NPF scenario should focus primarily on energy efficiency and environmental policy. In the worst case, such a policy would result in domestic crude oil production similar to that in the HVE scenario and the net light crude oil imports of about 20 Mm^3/d in 2007, at $35/bbl.

The energy industry would fare better under the NPF scenario than any other scenario. For example, increased environmental concerns would reduce the demand for heavy oil and increase the price differential between light and heavy oil making investment in synthetic crude plants less risky. Conversion of natural gas to more environmentally attractive transportation fuels would be less risky under the NPF than the HRD scenario, because in the

Table 27. CRUDE OIL DEMAND FOR TRANSPORTATION SECTOR (NPF)

	1987	1997	2007
Projected Demand Without CO_2 Reduction Mm^3/d	126.5	135	144
CO_2 Reduction Target, %	--	10	20
Crude Oil Demand Target, Mm^3/d	126.5	114	102
Amount of Crude Oil Reduced, Mm^3/d	--	21	42
Percent Required Reduction of Crude Oil Consumption	--	17	33

Table 28. SUPPLY AND DISPOSITION OF LIGHT CRUDE OIL, Mm^3/d (NPF)

	1987	1997	2007
DOMESTIC SUPPLY[1]	186	206	224
TOTAL DOMESTIC REQUIREMENT	212.9	192	172
NET EXPORT (IMPORT)[2]	(27)	14	52

[1] see Table 8 HRD Scenario

[2] does not consider alternative fuels production

HRD scenario the new fuels would compete with petroleum fuels on a price basis only, whereas in the NPF scenario, the new fuels would also be environmentally more desirable.

The opportunities for the petrochemical market would be mixed under the NPF scenario. As with the HRD scenario, Canadian producers would be facing rising prices for natural gas that are based on increasing costs of supplies frontier areas. Middle East producers will still have the benefit of low cost feedstocks and, although alternate primary energy markets are available, the ability to utilize the feedstocks to produce value-added petrochemical products will result in significant production from this area of the world.

Also, with the higher value for natural gas as a commodity, the use of CNG, rather than a converted product such as methanol, would be preferable under this scenario as an alternate transportation fuel. Methanol, when produced from a natural gas feedstock, shows a slight decrease in greenhouse gas emissions of 3 percent from base case gasoline and diesel fuels. CNG vehicles reduce emissions of greenhouse gases by 19 percent relative to the base case (Table 26). Further, methanol is more resource-intensive than CNG. Only 57% of the original natural gas energy is available to motorists through methanol conversion versus 84% for CNG taking into account losses in extraction, transportation and compression (Sperling & DeLuchi).

The market opportunity for MTBE, however, would be available as per the HVE scenario. The restrictions on RVP are the same for the two scenarios and therefore the requirements for the MTBE along with the availability of butanes would be similar.

An interesting question arises with respect to the options open to the refiners. The NPF scenario provides for strong oil prices, a surplus of light crude oil in Canada, a robust economy, an overall attitude of efficiency and maximizing the utilization of resources, and a high-tech approach to industry. There would quite likely be strong incentives for the refiners (i.e. vertically integrated oil companies) to invest in refinery modifications to produce high octane fuels that did not require non-petroleum based additives. Thus, although the NPF scenario will result in the more widespread use of non-petroleum fuels such as CNG, methanol, ethanol, additives such as MTBE, etc. as well as see the introduction of new transportation fuels such as hydrogen and electric vehicles, the conversion economics and the competition for the market place will be quite severe between various alternate fuels based on the conversion of natural gas.

The opportunities for the natural gas conversion to fuels and fuel components in the NPF scenario are as follows:

- application of CNG and natural gas derived fuels and fuel components as gasoline enhancers and extenders in household vehicles in order to reduce carbon dioxide emissions.
- use of CNG and other non-petroleum fuels to reduce carbon dioxide emissions from fleet vehicles, transit buses and truck freight.

- conversion of natural gas to methanol, ethane, etc., to reduce the transportation cost component for the exploitation of remote natural gas resources.
- use of natural gas based fuels in agriculture to reduce the cost and to increase environmental acceptability of fuel used by agriculture.

The constraints on the increased use of natural gas for conversion to alternate fuels in the NPF scenario are as follows:

- CNG makes more sense than conversion of natural gas to liquid fuels from the perspective of greenhouse gas emissions.
- strong incentives would exist for refiners to invest in refinery modifications to produce higher octane fuels that did not require non-petroleum based additions.
- vehicle efficiency improvements are even higher than for the HVE scenario due to increased fuel prices.
- slow progress on improved technology development for conversion of natural gas to fuel components with higher carbon and energy efficiency.

5.0. SUMMARY AND IMPLICATIONS OF THE SCENARIO ANALYSIS

5.1. Transportation Fuels Pricing, Demand and Market Characteristics

The average growth rate that resulted in each scenario for petroleum based refined fuels is shown in Table 29. The growth rates for total domestic use for the four scenarios range from -1.5 percent to +0.8 percent. The negative demand growth in the HVE and the NPF scenarios is due to the restrictions imposed on carbon dioxide emissions. Including the consumption of alternative fuels, the growth rate for the transportation sector is negative for the HVE scenario but positive for the NPF scenario (Figure 4).

As indicated, alternative fuels enable the transportation sector to maintain its growth under the NPF scenario conditions. The overall increase in energy consumption for the transportation sector is 0.8 percent in the HOI scenario, 0.7 for the HRD and NPF scenarios and -0.35 percent for the HVE scenario. This compares with an average +2.2 percent growth rate over the last twenty years (Figure 4).

The applied numerical values for the GDP and world oil prices, in the demand model, have resulted in consumption growth rates for refinery fuels being similar for the HOI and the HRD scenarios (Table 29). As could be expected, the high world oil

Table 29. PROJECTED AVERAGE DEMAND GROWTH FOR REFINERY FUELS (percent per year)

	HOI	HRD	HVE	NPF
Gasoline	0.5	0.5	-	-
Diesel and Aviation	0.9	0.8	-	-
HFO	-0.3	-0.6	-	-
Other	1.5	1.7	-	-
TOTAL TRANSPORTATION	0.7	0.6	-1.4	-1.5
TOTAL CANADIAN	0.8	0.7	-1.4	-1.5

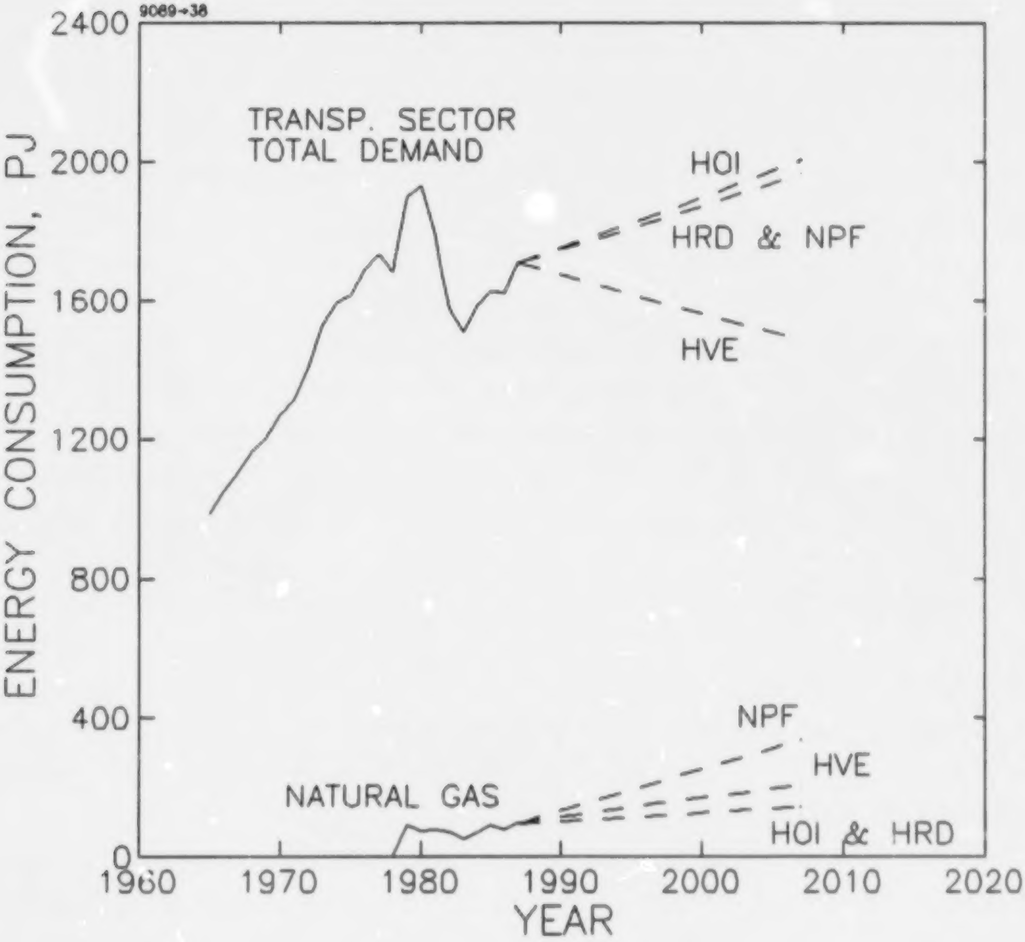

Figure 4. HISTORICAL AND PROJECTED ENERGY CONSUMPTION FOR THE TRANSPORTATION SECTOR

price scenarios did result in a faster decrease in heavy fuel oil demand and in lower diesel and aviation fuel demands than the low world oil price scenarios (Table 29).

Table 30 shows the projected relative changes in transportation fuel prices for each of the scenarios. Under the high environmental concern scenarios, the price of refined products increases at a faster rate than the price of world oil because of the additional taxation assumed for the refined products. In the HRD and the HOI scenarios, the gasoline and diesel price increases lag behind the crude oil price increases. This is the result of the fixed capital and operating costs associated with crude refining. For both the HVE and NPF scenarios, the additional taxation is on the fixed and variable fuel costs, which accentuates the strong, anti-consumption measures of fuel taxation.

Under all of the scenarios, crude oil remains the major source for transportation fuels. Even in the NPF scenario, crude oil supplies over 63 percent of the energy requirements for the transportation sector. However, CNG and other alternative fuels can become major players in selected areas such as gasoline additives, urban buses, vehicle fleets, or urban areas with severe air pollution problems.

Table 30. PROJECTED TRANSPORTATION FUELS PRICES (1987 = 100)

	1997			2007		
	Crude Oil	Gasol.	Diesel	Crude Oil	Gasol.	Diesel
HOI	109.6	105.7	116.7	120.0	114.3	123.3
HRD	132.5	122.9	123.3	175.0	151.4	153.3
HVE	109.6	117.1	130.0	120.0	125.7	140.0
NPF	132.5	148.6	150.0	175.0	182.9	186.7

Table 31 summarizes the total Canadian light crude oil requirements for each of the scenarios and the sources of supply. The alternate fuel sources are shown in Mm^3/d of light crude oil equivalent.

There are significant differences in the sources of supply between the scenarios. For example, the light crude oil import requirements vary from 9 to 17 Mm^3/d in the HVE and the HRD scenarios, to 93 Mm^3/d in the HOI scenario. The NPF scenario has exports of light crude oil in the amount of 75 Mm^3/d. The dollar value of the imports/exports and the alternate fuels is also interesting. Using the year 2007 import and alternate fuel requirements, and the world price of crude oil for the year 2007 in $ Cdn, 1987, the following figures result:

HOI scenario: imports - $5.1 billion per annum
alternate fuels - $330 million per annum

HRD scenario: imports - $1.4 billion per annum
alternate fuels - $400 million per annum

HVE scenario: imports - $500 million per annum
alternate fuels - $830 million per annum

NPF scenario: exports - $6.0 billion per annum
alternate fuels - $1.8 billion per annum

In all scenarios, the imports of light crude oil depend on the assumed values for GDP and world oil prices. These are the major factors that determine domestic supply and demand characteristics in the HOI and the HRD scenarios. In the HVE and

Table 31. CANADIAN LIGHT CRUDE OIL DEMAND AND SUPPLY IN THE YEAR 2007 (Mm^3/d)

	HOI	HRD	HVE	NPF
DEMAND	248	246	173	172
SUPPLY				
Conventional[1]	107	163	107	163
Synthetic[1]	42	61	42	61
Imports (Exports)	93	17	9	(75)
Alternative[2]	6	5	15	23[3]

[1] at 83 percent of production capacity

[2] Mm^3/d oil equivalent, the amounts indicate a minimum for transportation use only.

[3] total transportation sector energy demand is projected to be between 209 and 246 Mm^3/d equivalent depending on vehicle efficiency

the NPF scenarios, domestic supply and demand also includes the GDP and world oil price factors, but the environmental factor has a significant overriding effect on the domestic marketplace.

With the exception of remote natural gas, the opportunities for natural gas based transportation fuels do not increase with increased crude oil prices. The major factors behind the increased use of natural gas are environmental concerns which gradually allow a build-up of markets in urban transit, fleet vehicles, truck freight and agriculture. The major effect of increased oil prices is the exploitation of remote natural gas resources through conversion of natural gas to methanol, ethane, or other liquid fuels.

It is important to recognize that transportation fuel shortages are not projected for any of the scenarios. This is because the assumptions underlying the scenarios could not, in themselves, have produced oil shortages. Where alternate fuels were involved, in combination with oil, sufficient OPEC supply was assumed to always be available to meet the transportation fuel requirements. As a result, the focus for energy research and development strategies from this study has addressed issues such as energy pricing and diversity rather than supply shortages or security of oil supplies.

It is possible that shortages of some limited duration could occur, but over the 20 year timeframe considered, the demand/supply balances postulated did not result in any significant supply disruptions.

5.2. Alternative Fuels Supply and Market Characteristics

Table 32 summarizes the opportunities and constraints for conversion of natural gas to transportation fuels or fuel components. Alternative fuels appear in all four of the scenarios, but for differing reasons. Under the HOI and the HRD scenarios, they exist because the elimination of lead from gasoline has created a market for octane enhancers. There is also a limited need for alternate fuels to decrease exhaust emissions of carbon monoxide from gasoline powered vehicles and carbon monoxide and particulates from diesel vehicles in urban areas (urban transit buses). Under the HRD scenario, the alternate fuels are needed as octane boosters and to reduce carbon monoxide particulate requirements. In addition, there is a need to lessen the transport cost associated with exploitation of remote natural gas resources.

Under the HVE and the NPF scenarios, the majority of alternate fuels are required for the reduction of carbon dioxide emissions. The effectiveness of alternate fuels in terms of reducing carbon dioxide emissions varies widely. The study performed by de Luchi et al. (1987) concluded that using methanol from natural gas as a transportation fuel would not reduce the emissions of greenhouse gases from the transportation sector (Table 20). Assuming that there are no significant increases in vehicular efficiency and that vehicles powered by electricity from non-hydrocarbon fuel sources are not developed, only CNG shows promise for a significant reduction in greenhouse gases.

Table 32. SUMMARY OF OPPORTUNITIES AND CONSTRAINTS FOR NATURAL GAS BASED ALTERNATIVE TRANSPORTATION FUELS

SCENARIO	MARKET OPPORTUNITIES	CONSTRAINTS
High Oil Import Scenario	- gasoline enhancers - urban transit buses	- availability of low cost light crude oil
High Resource Development Scenario	- gasoline additives - remote natural gas - urban buses and fleet vehicles	- increased production and modification of petroleum refineries - good returns on natural gas sold to thermal markets
High Vehicle Efficiency Scenario	- gasoline additives - urban transit and fleet vehicles - truck freight	- poor economics of alternative fuels - lack of government initiatives for alternative fuels
Non-Petroleum Fuels Scenario	- gasoline extenders - fleet and urban vehicles and freight - remote natural gas - agriculture fuels	- higher than expected vehicle efficiency improvement - lack of advancement in natural gas conversion technology

Methanol used for the production of MTBE fits with all of the scenarios because of the common requirement for an octane enhancer. MTBE is the preferred gasoline extender and enhancer by refiners because it does not require modifications to the existing gasoline distribution network nor to conventional gasoline engines. However, MTBE does not effectively reduce carbon dioxide emissions because current methanol synthesis systems are highly inefficient. Under the HVE and the NPF scenarios, therefore, an important area for research would be the direct conversion of natural gas to methanol and to MTBE with higher carbon and energy conversion efficiencies.

The scenarios reviewed in this study have shown that methanol, because of its cost, has limited potential as an alternate fuel. Table 33 shows the projected methanol and gasoline prices for the four scenarios. The methanol prices are based on natural gas feedstocks in western Canada and Toronto, and the gasoline prices are based on world oil feedstock prices.

Since, in all scenarios, the price of natural gas moves up relative to oil, the best pricing opportunities for methanol occur in the mid-1990's. By the year 2000, methanol obtained from natural gas through conventional technology would encounter a significant pricing barrier to its use as a fuel component. There are several courses of action which industry might follow

Table 33. PROJECTED GASOLINE ENERGY EQUIVALENT PRICES FOR METHANOL[1] ¢/L

	1997	2007
HOI		
Gasoline	37	40
Methanol[2]	36-53	49-57
HRD		
Gasoline	43	53
Methanol	45-55	63-70
HVE		
Gasoline	41	44
Methanol	37-56	53-61
NPF		
Gasoline	52	64
Methanol	45-55	63-70

[1] based on Appendix B pricing equation, low range for fieldgate prices, high for Toronto prices, gasoline equivalent prices.

[2] in 1987 gasoline price ¢35/L, methanol ¢33/L - ¢45/L

in order to counteract the methanol price increases. These possible courses of action are discussed in Section 4.3, "Natural Gas Markets and Industry Characteristics".

With reference to Table 34, the future opportunities for CNG under the four scenarios are somewhat surprising and interesting. In 1987, the estimated break-even retail cost for CNG was about one-half of the then current price of gasoline. (Stephenson, 1988) However, in the year 2007, under the HVE, HOI and HRD scenarios, the projected breakeven cost for CNG is about two-thirds of the projected gasoline costs. This means that CNG would be less attractive from a pricing perspective under these scenarios in 2007 than in 1987. However, for the NPF scenario, the projected break-even cost for CNG remains approximately one-half of gasoline prices, suggesting that the NPF scenario entails the least economic risk for CNG as an alternate transportation fuel.

The alternative fuels and gasoline components should have the following characteristics to fit all the scenarios developed:

- an octane rating higher than 95 (blending (R+M)/2)
- moderate volatility with a rating less than 9 psia
- mid-range gasoline volatility should be maintained such as where butane has been removed through the addition of MTBE
- for cold engine starts, gasoline components should have improved front-end octane numbers. Currently only butane, alkylates and MTBE provide FEON's higher than 90 percent

Table 34. COMPARISON OF CNG BREAK-EVEN COSTS IN 2007 FOR ALL SCENARIOS

	N.G. PRICE[1] $/GJ	CNG BREAK-EVEN PRICES, ¢/L	GASOLINE PRICE ¢/L	BREAK-EVEN[2] CNG/GASOLINE
HOI	4.25	26	40	0.65
HRD	5.75	36	53	0.68
HVE	4.70	29	44	0.66
NPF	5.75	36	64	0.56

[1] Toronto

[2] 0.51 for 1987

The risk associated with the development of these fuels is very closely related to world oil prices and to the relative pricing of natural gas versus petroleum based products. Higher world oil prices and higher domestically priced transportation fuels will provide greater opportunities for natural gas conversion. However, in all of the scenarios, natural gas follows the price of oil; in fact its price moves up relative to the price of oil. Therefore, government policies regarding the taxation of transportation fuels from various sources will be an important factor in determining whether alternate fuels are developed.

Increased energy efficiency and conservation efforts in the transportation sector would benefit this same sector under all the scenarios. Under the low oil price scenarios these factors would help reduce imports of light crude oil. Under the high oil price scenarios, decreased domestic consumption of premium-priced resources would lead to an increase in the net export of energy products such as light and heavy crude, natural gas and electricity. Under the high environmental concern scenarios, increased energy efficiency and conservation in the transportation sector would make it possible to improve the environment without spending large sums of money on pollution control devices and without restraining the economy because of the overwhelming costs of these devices.

The implementation of environmental controls to reduce emissions from equipment and systems already in place typically involves high capital and operating expenditures and results in higher energy cost than would implementation of efficiency and conservation measures. Environmental measures that rely primarily on energy conservation would, therefore, result in decreased cost and an improved economy.

5.3. Natural Gas Markets and Industry Characteristics

Figure 5 shows projected natural gas prices for the various scenarios. The projected gas prices are based on price and demand projections compiled by the NEB, CERI, GRI and the AERCB. Under all of the scenarios, the price of gas is determined by demand versus increases in production and transportation costs from incremental new reserves.

The movement of natural gas prices relative to oil in the different scenarios is as follows:

1. Under the low GDP growth and low oil price HOI scenario, price of natural gas reaches parity with oil because of the depressed level of oil prices; there are no real drivers pushing the price of gas up.
2. Under the high growth and high oil price HRD and NPF scenarios, the price of gas accelerates more quickly, particularly in the early 2000's because of an increasing need for production of gas from the more expensive frontier areas and because of higher oil prices which allow quicker recoveries in gas prices. Natural gas is also on par with oil at the end of the HRD scenario time-frame.
3. Under the higher environmental protection HVE scenario, the price of gas increases to a point where it is priced at 120 percent of oil. The premium price is possible because of the perception that natural gas is the most environmentally benign hydrocarbon fuel. The premium in price will not be large enough to cause any major shifts in energy use patterns.

A key element of all of the scenarios is the availability in Canada and the United States of significant additional volumes of natural gas from conventional and frontier areas as the price of natural gas increases. As indicated in Section 1.0, Volume 2 of

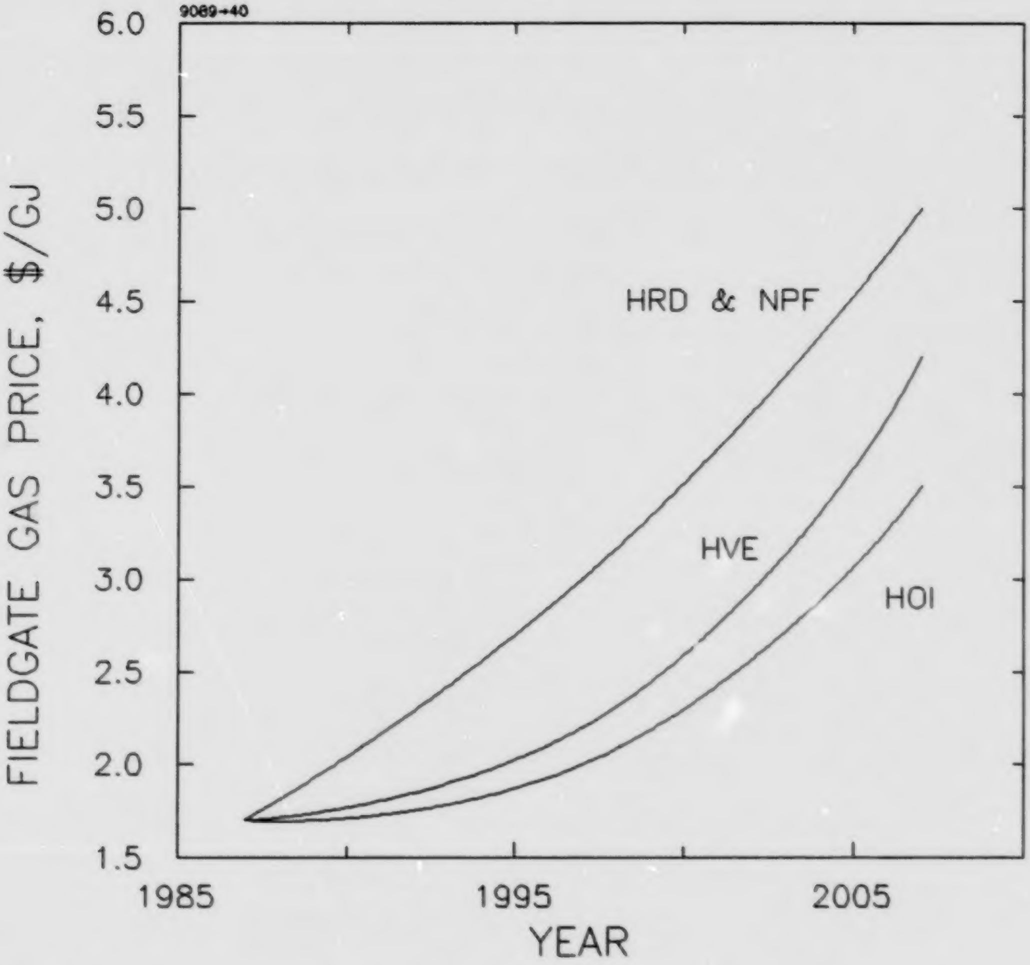

Figure 5. **PROJECTED NATURAL GAS PRICES FOR DIFFERENT SCENARIOS**

this Report no major technological constraints on the exploitation of Canadian resources were identified. However, the lack of pipeline facilities from new production areas is a possible constraint.

The increases in natural gas prices relative to oil creates economic barriers for alternative fuels in all four of the scenarios. The relative price increases could be countered through technological advances that allow decreases in natural gas exploration and production costs, technological improvements in natural gas conversion technologies, and possible strategic options such as vertical integration and remote-site utilization of natural gas. The likelihood is good that industry will undergo the changes necessary to implement these improvements, thus resulting in the HRD and NPF scenarios (see "Structural Changes and Key Issues" in these scenarios). For the low world oil price scenarios (HOI and HVE), industry's adjustments may be more difficult, with the exception of more vertical integration, to secure long term low-cost feedstocks.

A significant element in all of the scenarios is the export of natural gas to the United States. It is of interest that the level of export remained relatively constant under all of the scenarios, from a low of 47 x $10^9 m^3$/y in the HOI and the HVE scenarios to a high of 51 x $10^9 m^3$/y in the HRD and the NPF scenarios. A discussion of the reserves addition levels and the export market requirements is contained in the discussion of the HRD scenario. (Section 4.3 in Volume 1 of this Report)

As noted earlier, crude oil remains the major source for transportation fuels in all of the scenarios. The use of natural gas either as CNG or as a feedstock for alternate fuels will therefore have to be targeted at specific areas of application such as urban transit, fleet vehicles, etc. The opportunities and constraints for the specific areas of application are not readily apparent when the transportation sector is considered for Canada as a whole.

The reasons for this are twofold: 1) the analysis performed for crude oil demand was based on demand for commodity markets such as (gasoline, middle distillates, etc.) and not for different transport areas; and 2) although the market size for alternative fuels is determined by economic (GDP and world crude oil price) and environmental factors, the actual penetration of this market is heavily dependent on government (see "Major Constraints Associated with Markets", Section 7.1 of volume 2 of this Report). This is explained further below.

In the HOI and HRD scenarios (Table 32), the market for alternative fuels was limited to the gasoline additive market and, possibly, to small market niches like urban transit. The development of the gasoline additive market would not likely result in the penetration of alternative fuels to other transportation areas. In the HVE and NPF scenarios (Table 32), the markets are increased by fleet vehicles and the need for gasoline extender for household vehicles. However, two important factors led to these projections: 1) a higher concern about environmental issues including the greenhouse effect; and 2) high government intervention in regulating carbon dioxide emissions. It is apparent, therefore, that government involvement is necessary if there are to be opportunities for the alternative fuels.

It is also apparent that market forces alone are not likely to result in penetration of alternative fuels beyond the gasoline additives and selected niches market. In addition to having economic disadvantages, fuels which are dissimilar to petroleum fuels have a number of other disadvantages. They are subject to the risk which accompanies any new fuels technology. They tend to be rejected by conservative vehicles owners, and the inertia of the transport system works against their use. The optimum R&D strategy in the scenario of low government involvement would, therefore, call for research on gasoline additives. A technological breakthrough in the production of dissimilar fuels would need to be accompanied by a commercialization plan aimed at overcoming the non-economic disadvantages of these fuels.

Table 35 summarizes major opportunities and constraints for natural gas under the four scenarios. Of special interest are the HRD and the NPF scenarios. Under the HRD scenario, the

Table 35. MAJOR OPPORTUNITIES AND CONSTRAINTS FOR NATURAL GAS USE FOR ALL SCENARIOS

	HOI	HRD	HVE	NPF
ADVANTAGES OF NATURAL GAS	Reduces Balance of Payment for Imported Light Crude Oil	Less Risk Involved than for Synthetic Crude Due to Lower Front Load Cost	Reduces CO_2 Emissions Without Reduction of Energy Consumption	Most Attractive Feedstock for Alternative Fuels
MAJOR COMPETITORS TO NATURAL GAS				
Transport Sector	OPEC Oil	Frontier and Synthetic Crude	High Vehicle Efficiency	Renewable Energy Sources
Industrial Sector	OPEC Oil	Coal	Conservation	Renewable Energy Sources
Commercial & Residential Sector	Electricity	Electricity	Conservation	Electricity Based on Renewables

exploration for and the utilization of natural gas versus the construction of synthetic fuels plants would favour the use of natural gas. In the NPF scenario, the use of renewables would be in competition with natural gas, but the capabilities of renewables to meet transportation energy requirements would be fairly limited. Hence natural gas would be the preferred feedstock for alternative, non-polluting transportation fuels.

5.4. Petrochemical Market

Petrochemical prices in Canada are affected by global supply and demand fluctuations. Canada has a modern petrochemical industry and access to secure low cost natural gas supplies as well as off-shore oil at world prices.

However, Canada will be very susceptible to the pressures brought about by the increases envisioned in each of the scenarios in natural gas costs relative to oil and by the presence of new, export-oriented low feedstock producers particularly those from the Middle East.

Figure 6 shows historic demand patterns for selected feedstocks and chemicals in Canada. Both Canada and the United States have relatively mature markets for most petrochemicals. The conversion of ethylene and benzene into bulk petrochemical products is well established as is the downstream conversion of methanol into other products.

The issues for the Canadian petrochemical industry under the four scenarios are similar. Existing markets will have to be maintained through increased efficiency and/or new technology in the face of the emerging new competitors with feedstock pricing advantages. In addition, new specialized petrochemical markets with more value-added product potential will have to be established to offset increasingly higher capital, operating and feedstock costs.

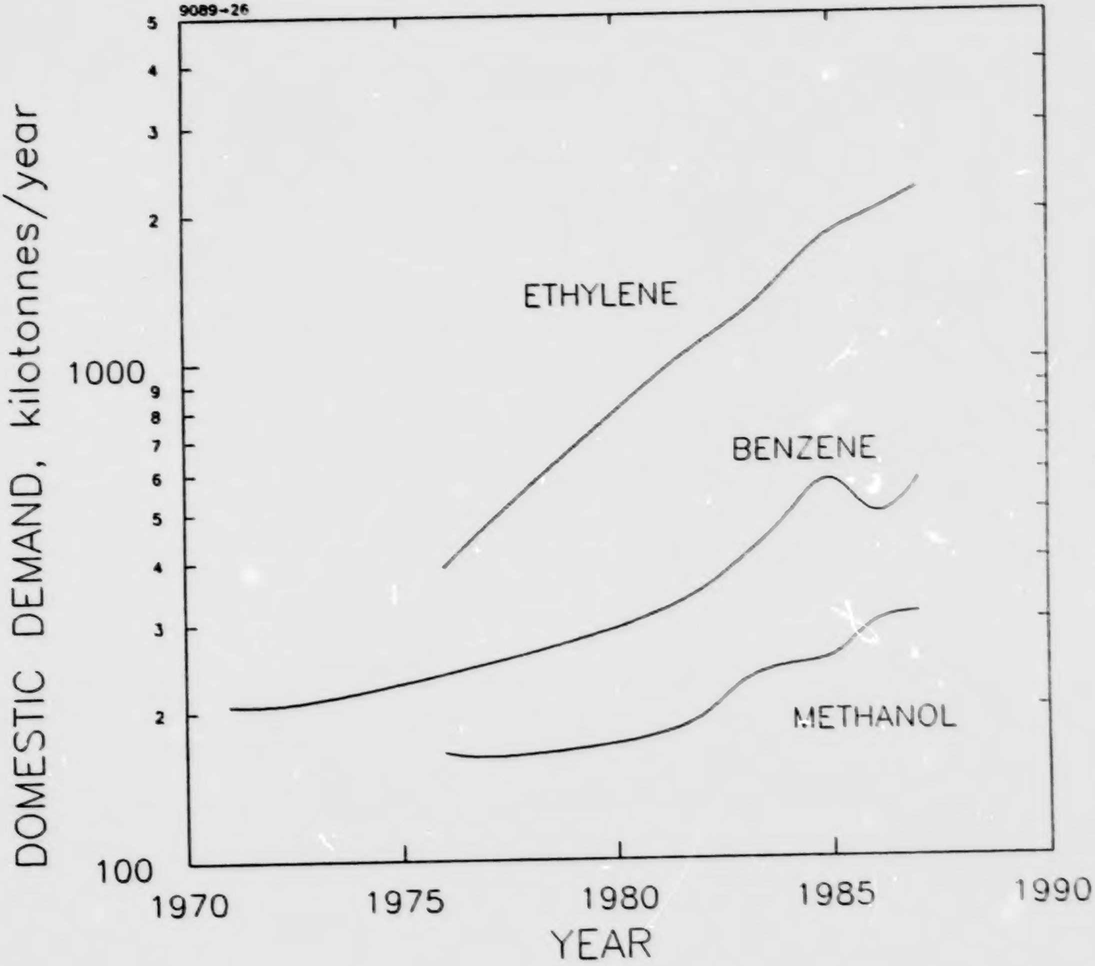

Figure 6. **CANADIAN DEMAND FOR SELECTED FEEDSTOCKS AND CHEMICALS**

Low cost competitors will not have completely free access to the North American marketplace. Canada, because of her free trade agreement with the United States, will not be subject to a number of the trade barriers which exist in the world petrochemical market. As well, it is expected that competitors from third world countries will have to face tariff barriers upon entering the North American market.

Strong growth could be expected in areas such as engineering plastics and high performance synthetic fibres, and in the use of MTBE as an octane boosting fuel additive.

With the rising cost of landfill and of incineration of municipal solid waste, there is increased effort to reduce waste by recycling plastics. The most commonly used thermoplastics such as polyethylene, polyethylene terepthalate, polystyrene and polypropylene can all be recycled. Recycling of these products is done to a limited extent. However, under the HVE and the NPF scenarios, government policies would emphasize recycling. At present, plastic constitutes about 30 percent, by volume, of municipal solid waste. (Thayer, 1989)

Technology has been and will be the key approach for the petrochemical industry in coping with changing feedstock and energy prices, increased maturity of existing market areas and the development of new, high value added product areas. The focus under the high environmental concern scenarios will also include the development of technology to make petrochemical products more environmentally acceptable either from the point of view of the production process itself or from the point of view of the end-use products.

5.5. Impact on Methane Conversion Research and Development

The scenario analysis performed in this study shows that there are a number of underlying, cross-scenario rationales for the development of alternate fuels from natural gas, namely:

1. Canadian conventional crude oil reserves are declining and the development of frontier reserves, heavy oil and synthetic crude oil is expensive and will not necessarily occur.

2. Petroleum derived fuels will continue to supply the major portion of the transportation sector's energy demand in all four of the scenarios evaluated.

3. Canada and the United States both have significant natural gas resources that can be brought on stream as the price of oil increases. The availability of the gas resources places a ceiling on possible price increases for both natural gas and crude oil. For natural gas, the ceiling is established by gas-on-gas competition. For crude oil, the ceiling is established by the ease with which alternate fuels can be created from natural gas.

4. Significant crude oil imports occurred under the HOI scenario. Further, none of the scenarios considered any degree of dislocation in the supply/demand balance for light crude oil. Even a small dislocation could bring the energy security issue into focus.

5. The development of alternative fuels would provide some diversity and security of supply.

6. Environmental considerations such as the removal of lead from gasoline, and the reduction in vehicle exhaust emissions such as nitrous oxide, sulfur dioxide, carbon monoxide and hydrocarbons from gasoline and diesel powered vehicles will increase under all scenarios as the general public becomes more concerned about protecting the environment.

7. The removal of lead from gasoline and concerns over carbon monoxide emissions and particulates from gasoline and diesel powered vehicles will provide opportunities for methanol and MTBE in all scenarios.

8. Environmental concerns over carbon dioxide will not provide an incentive for alternative fuel production from natural gas by conventional technology. CNG is the only hydrocarbon-based alternate fuel that actually reduces CO_2 emissions. New technology is required for the conversion process and

the direct conversion route holds more potential for a breakthrough than the indirect conversion route.

9. The development of alternative non-petroleum based transportation fuels in the NPF scenario allows Canada to become a significant net exporter of light crude oil. The lack of such an alternative under this scenario would have a strong detrimental effect on the overall Canadian economy.

10. Alternate fuels and technologies could be important to the Canadian economy and could make possible the export of new technologies & both petroleum and non-petroleum based fuels.

Also, the scenario analysis shows specific opportunities or market niches related to the individual scenarios, namely:

1. Use of natural gas conversion technologies to reduce the transportation cost component during exploitation of remote natural gas resources in the HRD and NPF scenarios (conversion to methanol, ethane, etc.).

2. Use of natural gas based fuels for truck freight with the HVE and NPF scenarios as a means to maintaining the sustained growth of this industry while reducing the consumption of petroleum based fuels as mandated by the government to reduce carbon dioxide emissions across the transportation sector.

3. Use of natural gas based fuels for fleet vehicles in the HRD, HVE and NPF scenarios as a means to reduce the cost of transportation fuel or to reduce the carbon dioxide emissions by the sector.

4. Use of natural gas based fuels in agriculture in the NPF scenario to reduce the cost and increase environmental acceptability of agricultural fuels.

5. Use of natural gas based fuels in household vehicles in the NPF scenario in order to comply with government regulations on reduction of carbon dioxide emissions. This market is also the largest potential market for alternative fuels.

The most important benefits of energy research and the development of alternative fuels are seen to be: 1) the imposition of a ceiling on transportation energy costs, 2) the diversification of the supply of transportation fuels, 3) the development of environmentally sound alternative fuel technologies which would permit higher levels of economic growth based on alternate forms of energy and more efficient energy utilization, and 4) the reduction of the risk involved in development of synthetic fuels (e.g., CNG vs synthetic crude from bitumen).

Since the transportation sector is a low-growth market, new fuels would have to take a market share away from the existing fuels, either by replacing them or through improvement of the environmental aspects of their utilization (gasoline additives). Therefore, fuels or fuel components that are very similar to petroleum fuels (e.g., synthetic crude, MTBE, etc.) or have an existing distribution network (e.g., natural gas for CNG) are more likely to be used. Alternative fuels that need new distribution, transmission and end-use technologies (e.g., hydrogen) would have disproportionately higher implementation barriers and any research in this area would require a commitment from government not only for the R&D phase but also to get a foothold in the marketplace.

Oil will remain the major source of transportation fuels in Canada over the next twenty years. However, natural gas and natural gas based alternate fuels will be advantageous in specific applications such as gasoline enhancers and extenders, urban transit, fleet vehicles, etc. In order to identify the extent, timing and implementation of natural gas conversion technologies in different energy areas, a further set of decision or planning scenarios is required. This is necessitated by the fact that although economic and environmental factors determine the size of the potential markets for alternative fuels, the actual penetration of these markets is determined by government involvement and by the extent and type of government regulations and policies.

A second set of scenario analyses, to focus in more detail on the government involvement and technology assessment framework identified in this study, is recommended for future work.

6.0. RECOMMENDATIONS FOR FUTURE WORK

This section presents recommendations for work on decision scenarios which support the development of a framework for planning strategic R&D on conversion of natural gas to liquid fuels and fuel components. The specific scenarios are to provide a framework which will allow the planner to identify goals for targeted R&D programs.

6.1. Effect of Regional Differences

The supply, demand and price projections for transportation fuels in this study were done for all of Canada without any consideration for regional differences. The "broad brush" approach results in a loss of information regarding regional opportunities which may be quite different from the overall Canadian opportunity.

For example, under the HRD scenario, the production of transportation fuels from biomass may seem uneconomical at \$0.48/L versus \$0.43 to \$0.53/L for gasoline (Tables 21 and 16). However, biomass could be attractive in regions such as Quebec and New Brunswick which have biomass advantages. A further example is CNG in western Canada where lower natural gas prices could make more widespread use of CNG economically attractive at an earlier date.

Since each region is characterized by its own mix of energy supply and consumption requirements, different opportunities will exist under the various scenarios.

A scenario analysis on a regional basis should include a review of the applicability of the demand equation for each region using historical information on economic growth patterns, availability and disposition of petroleum based products, and pricing of alternate energy products.

Differences in response to energy price increases and environmental constraints should also be considered on a regional basis. Particular areas of interest would be natural gas versus coal in western Canada, heavy fuel oil versus natural gas and electricity in Ontario and Quebec, and the use of renewables in remote areas.

Other regional differences that should be evaluated include provincial energy resource considerations, government involvement in economic and energy development, the type of industries in the regions and the degree of diversification of the various economies. These considerations would almost certainly affect the type of response that is possible and the type of response that may be expected under each scenario.

6.2. Effect of Dislocations and Sudden Changes

As was pointed out earlier, in the learning scenarios developed in this study, the effects of a sudden dislocation in one of the major assumptions was not considered. For example, a sudden disruption in imported light crude oil supplies, an abrupt increase or decrease in crude oil or natural gas prices, or a lack of continuity in energy prices such that investment climates are too uncertain to allow for necessary investments in the Canadian energy resource sector.

Even where the average change in crude oil and natural gas prices may be close to that projected for the scenario, price oscillations could have a profound effect on the scenario outcome, particularly in scenarios like the HRD and the NPF cases. Therefore, dislocations to the key assumptions should be evaluated as part of any future scenario analysis.

The world oil price ranges used in this study were based on econometric data generally accepted by various forecasting organizations. The oil prices and natural gas prices could be significantly different from those assumed in the various scenarios. Future work should therefore include an assessment of what effects, if any, significant departures from the assumed prices would have.

The effects of the time required to respond to significant dislocations should also be addressed. In this study, factors such as GDP and oil prices were projected in a uniform and predictable pattern leaving sufficient time for market adjustments. In future work the dynamic character of changes to the energy supply/demand balance and pricing should be considered.

6.3. Response of Petrochemical Industry

The effect of different scenario factors on the petrochemical industry was not explored in sufficient detail. The availability and pricing of feedstocks was addressed and the some of the existing petrochemical product areas considered. However, the new product areas where higher value-added end-uses for natural gas can be achieved has been identified as one of the key responses of the petrochemical industry in this study. Future work should address the existing mature bulk product markets as well as the potential new market areas.

Also of interest is how the factors of high environmental concern and conservation will affect petrochemical processes, products and market demands. These areas should be addressed in more detail. In addition, more detailed profiles on the perceived major competitors of the Canadian petrochemical industry should be prepared and the likely responses of each of these competitors to the changing scenario assumptions should be addressed.

6.4. Effect of Social and Government Policy Constraints

The four scenarios completed were based, in general, on the economic view of the energy and transportation fuels markets. The scenarios explained market forces such as economic growth and world oil prices combined with a qualitative cost analysis of broad fuel commodities and several environmental factors. The outcome of the analysis was the list of opportunities and constraints for R&D on natural gas conversion technologies. The approach based on the economic view of the long range energy R&D has, however, a major weakness; the long time required between the research planning and commercialization of energy technologies (about 20 years) could make many of today's market assumptions obsolete and unimportant for future energy supply and demand. This is because society's values and goals, and with it government policies, often change over a period of 20 years. We recommend, therefore, that one more theme be considered in the scenario analysis which addresses the implementation barriers for alternative fuels. The theme: "Social and Government Policies Constraints", would furnish the necessary third dimension to the analysis of the strategic R&D issues in alternative fuels (Figure 7).

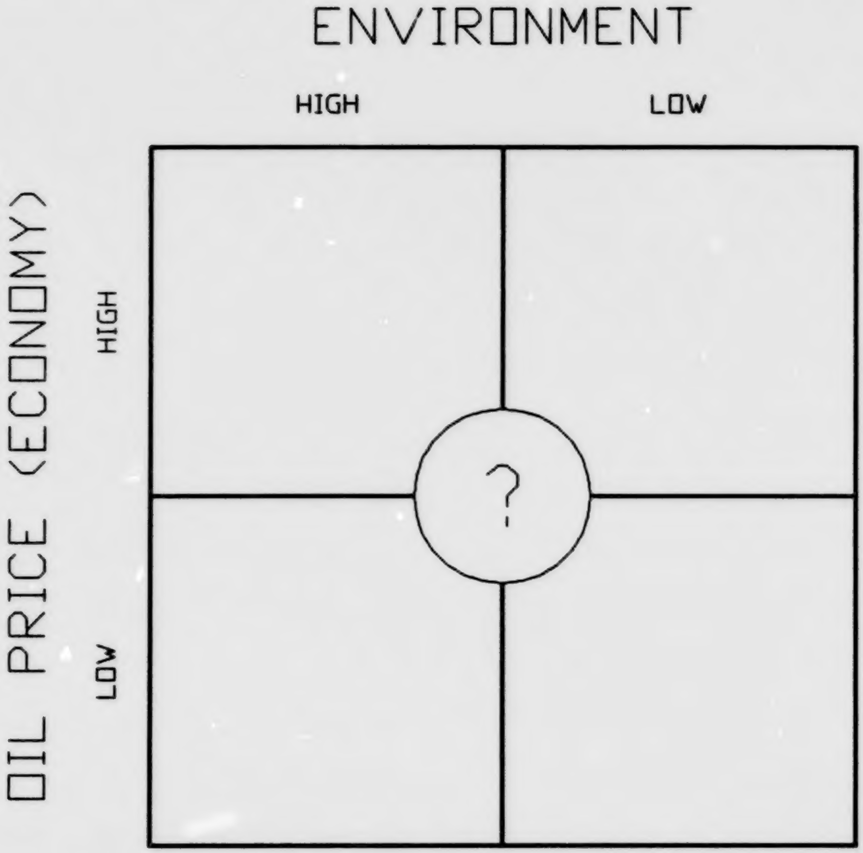

Figure 7. **PROPOSED SCENARIO MATRIX FOR DECISION SCENARIOS**

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Appendix A - LIST OF VARIABLES AFFECTING CANADIAN ENERGY SUPPLY AND DEMAND

1.0. TRANSPORTATION FUELS

1.1. Technology

- efficiency of vehicle stock (gasoline and diesel engines, new versus existing vehicles and rate of replacement).
- pollution control equipment for internal combustion engines.
- availability of supply and distribution systems for alternate fuels (propane and CNG).
- improvements in refining techniques for conventional light oil.
- increased capacity for refining heavy oil.
- availability of public transportation systems.
- ethanol, methanol and MTBE as octane enhancers.
- conversion of coal to gas/oil products.
- conversion of natural gas to liquid fuels.
- hydrogen production, handling and end-use technologies.
- electric powered vehicles (battery).
- improvements in biomass conversion to ethanol.
- dual-fuel motor engines developed.

1.2. Environmental

- elimination of lead from gasoline.
- use of alcohol/gasoline blends or CNG where atmosphere conditions necessitate reduced NO_x, CO and hydrocarbon emissions (i.e. Los Angeles, New York City buses, etc.).
- pollution control standards for internal combustion engines.
- reductions in particulate and NO_x emissions from diesel engines.
- limits on benzene levels in gasoline.

- RVP phasedown to lower evaporative HC emissions.

1.3. Social/Political/Economic

- relationship between demand for transportation fuels and GDP, degree of residential segregation & level of private vehicle ownership.
- growth in trucking and airline industries (deregulation).
- prices for gasoline, diesel and alternate fuels (price elasticity and fuel interchangeability).
- federal and provincial taxes on transportation fuels.
- government incentives to encourage development of alternate fuels.
- oil as a strategic commodity for transportation fuels.
- various levels of government policy towards transportation methods (i.e. rail freight rates versus trucking at federal and provincial levels, public transit at provincial and municipal levels).
- growth of GDP and maturity of the economy.

2.0. NATURAL GAS

2.1. Technology

- availability of gas transmission and distribution pipeline infrastructures.
- size and efficiency of equipment stock (new versus existing and rate of addition and replacement).
- dual fuel capacity of industrial and commercial equipment.
- new (or improved) gas use technologies - i.e. low first-cost gas fueled cooling equipment, gas fired cogeneration and combined cycle systems, more efficient gas combustion equipment (furnaces and boilers).
- efficiency of housing and commercial building stock (new versus existing and rate of additional replacement).
- increased use of natural gas as means to control SO_2/NO_x emissions.
- exploitation of "tight" sands gas reserves in western Canada.
- improved exploration and production techniques in both conventional and frontier areas.
- increased use of natural gas a source of hydrogen for heavy oil upgraders.

2.2. Environmental

- development of sour gas reserves in conventional areas.
- stringency of regulations affecting exploration, production and transportation from arctic and offshore areas.

2.3. Social/Political/Economic

- burner-tip price for natural gas and price of near substitutes (price elasticity and fuel interchangeability).

- current over-supply of gas in North American market.
- no market or regulated tie between natural gas prices and world oil prices.
- government incentives for conservation and efficiency improvements in housing and industry.
- government programs to switch "off-oil".
- political intervention or lack thereof re: pricing, exports and access to transportation systems.
- short term versus long term supply contracts and the emergence of new marketing mechanisms with deregulation of the gas industry.
- size of gas resources in Canada and N. America (conventional and frontier).
- increasing costs for incremental supplies from Canadian reserves.
- taxation policies (federal and provincial) and drilling incentives.
- relative transportation cost difference between U.S. and Canadian supplies.
- rate of inflation and interest rates (price of gas at the wellhead and the effect on end-user investment decisions).
- changes in economic activity (GDP) versus demand for natural gas.
- ability of Canadian petrochemical industry to compete in world markets.
- government expenditure and deficit and how these affect GDP.
- exports of gas to certain parts of the U.S. are constrained by pipeline capacity - level of Canadian exports.
- natural gas share of Canadian energy demand.
- cost of finding and developing of new reserves.
- revenues from NGL and sulphur (20-25% of N.G. revenues, can make marginal gas plays economic).
- cost of transportation from frontier region ($1.26 per MCF (1986) Cdn.).

- household income (size of housing and energy uses) and demographics.
- average daily temperatures (seasonal and year by year variation).
- seasonal and long term changes in commercial and business activity (business cycles).
- U.S. FERC policies (zone rate structure for gas carriers, etc.).
- regional demand for natural gas in U.S. (two frontier resources will serve different areas).
- premium that buyers are willing to pay for long-term secure supplies (consumer expectations).

3.0. OIL

3.1. Technology

- efficiency improvements in gasoline and diesel powered vehicles.
- improved techniques for mining of bitumen and on-site production of heavy oil.
- improved enhanced oil recovery techniques.
- improved exploration and production techniques in both conventional and frontier areas.
- more efficient oil combustion equipment (rate of replacement).
- use of coal for bitumen recovery and upgrading (generation of steam and as a source of hydrogen).

3.2. Environmental

- stringency of regulations affecting exploration, production and transportation from Arctic and offshore areas.
- sulfur, NO_x, CO and CO_2 problems for combustion end-use.
- massive scale of bitumen mining and oil sands processing plants (sulfur emissions, tailings disposal, water contamination).

3.3. Social/Political/Economic

- world price for crude oil, various refined petroleum products in Canada and price of near substitutes (price elasticity and fuel interchangeability).
- conversion and structural changes in Canadian economy resulting from oil price shocks (size of increase necessary to create a shock).
- government "off-oil" policies, conservation and efficiency programs.

- current over-supply of oil in world markets and diminished OPEC market position.
- level of Canadian imports and exports (light and heavy crusher, refined products).
- market forces to determine oil prices (world pricing)
- political intervention re: pricing, exports and imports (or lack thereof).
- security of supply considerations on oil imports.
- decline of conventional oil reserves; existence of significant bitumen and heavy oil resources in Canada.
- increasing costs for incremental oil supplies from Canadian reserves.
- government involvement in mega projects and in the development of new technologies taxation policies (federal and provincial) and drilling incentives.
- rate of inflation and interest rates on wellhead prices and on end-user investment decisions.
- changes in GDP and demand for refined oil products.
- oil's share as a percentage of total energy demand in Canada.
- upward and downward price elasticity for the oil demand.
- Time-lag between changes in price expectations and crude oil supply and projects underway.
- Canada's production of light crude oil peaked in 1973.
- large Canadian reserves of bitumen and heavy oil. The fastest growing source of oil supply over the last five years has been the production of bitumen.
- exploration in Canada's conventional areas is mature and approx. 85% of original conventional oil has been discovered. Exploration in frontier areas is new and approximately 10% of the estimated resource base has been discovered.
- effect of world demand for oil on price of oil in Canada and on the nature and the timing of oil projects in Canada (conventional, frontier, bitumen, in-situ and enhanced oil recovery.)

- presence of government assistance for oil development projects where significant market uncertainties exist for private investors.

- Growing Canadian dependence on imports of light crude oil which are dedicated to home heating oil and transportation fuels.

- the bottom of the world's oil barrel is in sight (50 to 90 years) and oil will no longer dominate the global energy market.

- effect of world oil prices on Canadian refinery addition capacity.

4.0. COAL

4.1. Technology

- development of new or improved clean combustion technologies.
- beneficiation of western Canadian thermal coals.
- beneficiation of north-eastern U.S. thermal coals.
- reduced transportation costs via unit trains, pipelining of coal.
- development of coal-oil and coal-water slurries as combustion fuels.
- co-processing of coal and oil.

4.2. Environmental

- sulfur, NO_x, CO and CO_2, particulate emissions and ash disposal problems for combustion end-use.

4.3. Social/Political/Economic

- government policies on use of coal for electrical generation in Ontario (versus nuclear power).
- relationship between demand for coal and world oil prices.
- increased electrical exports to the U.S. based on coal-fired generation.
- convenience of coal use (coal is the least desirable conventional hydrocarbon fuel because of costs for storage, handling, waste disposal and environmental costs).
- rate of inflation and interest rates (effect on life cycle costing versus use of near substitutes).
- transportation costs to ports (severely disadvantage Canada in the international thermal coal market).

- effect of low world oil prices on the development of new technologies for the use of coal as a substitute for oil (liquefaction, gasification, etc.).
- ability to forecast electric demand growth and selection of generation mixed technologies.

5.0. ELECTRICITY

5.1. Technology

- increased use of high efficiency electric motors in industry.
- more efficient appliances and lighting in residential and commercial sectors.
- more downstream use of electro-technologies because of availability and flexibility of electricity.
- rail electrication in urban areas.
- better grid inter-ties (interprovincial and with U.S. export markets).
- HVDC and superconductivity transmission systems.
- development of isolated hydroelectric sites.
- development of technologies to produce power via fusion, tidal power, photovoltaic wind generation.

5.2. Environmental

- large scale, centralized generating facilities and their associated distribution systems raise environmental concerns whether coal, nuclear or hydro generation.
- hydro is renewable and has significant potential to be developed in Canada but it is ultimately limited as a resource potential.
- increased coal-fired generation, especially in Ontario has well recognized environmental problems ("greenhouse" effect could have severe ramifications for coal-fired electrical generation)
- nuclear power plants suffer from problems with public perception and methods for the safe, long-term disposal of nuclear wastes.

5.3. Social/Political/Economic

- increasing exports of electrical power to the U.S. not only as a pre-build option but also as a "manufactured" product.
- significant coal, hydro and uranium resources and world class technological base in Canada for the generation, transmission and use of electricity.
- movement in Canadian economy to more service oriented economy shifting more emphasis to use of electricity vs. GDP.
- regulated price for electricity in most parts of Canada.
- underpriced electrical exports (does not include various social and environmental costs).
- lack of a national perspective on the planning and utilization of generating facilities and better system inter-ties.
- use of demand management & rate design to improve load management and efficient use of generating facilities.
- emergence of non-utility suppliers of power; industrial cogenerators and independent power producers.
- use of provincially owned utilities as instruments for social policy.
- changes in GDP and demand for electricity.
- regional differences in the effect of changes in world oil prices (low prices benefit central and Atlantic Canada and hurt western Canada; high prices have the opposite effect) and the resulting demand for electricity.
- effect of interest rates and rate of inflation on life cycle costing decisions by end-users.
- electricity has increased its share as a percentage of final energy demand since 1973.
- new electrical generating capacity has a long planning horizon (typically 5 to 8 years).

6.0. GENERAL VARIABLES

- Canadian energy requirements are being supplied from multiple energy sources that are becoming more dedicated to specialized users.
- Canadian energy market is basically deregulated inter-provincially and for the most part it already operates in a free-trade environment with the U.S.
- in response to the oil-price shocks of the 1970's and early 1980's, there have been and there continues to be, significant increases in efficiencies for residential housing, commercial buildings and end-users, all modes of transportation and industrial energy intensity.
- structural changes are taking place in the Canadian economy as it moves to a "post-industrial" stage; i.e. away from smoke-stack, energy-intensive primary industries towards service based economy.
- externalization of trade conditions and their world debt problems will increasingly affect Canada's open economy (interest rates, inflation, GDP, trade balance).
- the degree of government involvement in the Canadian economy and in the energy industries (deregulation, privatization, allowing market forces to prevail versus regulation, public ownership and control of markets through government intervention).
- co-ordination of federal and provincial policies and taxation regimes.
- effects of an aging population, changes in labor force and productivity on energy demands (link to GDP).
- oil as a strategic commodity for areas where an alternate to oil is not readily available.
- renewable energy sources have been undercut by current cheap energy supplies.
- stiffer environmental laws on a global basis re: acid rain, CO_2 (greenhouse effect), ozone layer depletion and pollution of the oceans.
- sustainable development and the effect on energy demand; increased electrical requirements and decreased hydrocarbon usage.

- effect of climate on a seasonal basis for energy demand; regional basis; effect of global warming on energy forms required in Canada and the world.
- time required for structural changes in the economy (fuel interchangeability, demand levels, energy use intensity) in response to price shocks, environmental concerns and government policies.
- adjustments in Canadian and other OECD countries to the oil price shocks have resulted in the more efficient use of energy per unit of economic output i.e. economic growth is not dependent on an equivalent growth in energy consumption.
- fuel diversification capabilities at the burner-tip intensifies interfuel competition.
- the use of advanced technology for industrial, commercial and residential applications will further energy efficiency gains.
- energy technology development takes a long time. Applied research through to proven options may take a couple of decades.
- energy technology deployment takes an even longer time. Energy supply technologies have long lifetimes i.e. oil refineries and thermal electrical generating plants have lifetimes in the order of 25 to 30 years. Buildings and hydro-electrigeneration plants have lifetimes in the order of 50 years.
- the clear direction of regulation in N. America is to do less of it. This helps to eliminate "regulatory lag" which is a significant factor in a volatile international market.
- a private firm's perception of risk is likely to differ from society's.
- government regulation and subsidies distort energy prices and may send the wrong signals to the market place.
- government regulation is becoming less based on economic aspects (i.e. entry and prices) and more on social aspects (i.e. environmental and safety).
- the U.S. will become more reliant on imports of oil and gas as their own production of these commodities declines.
- a large growth in U.S. imports of energy may not occur.
- there are physical and regulatory constraints on the movement of crude oil, natural gas and electricity across Canada and into the U.S.

- in both the conventional and frontier regions of Canada, established gas reserves are more than twice as large, on an oil equivalent basis, as crude oil reserves.

- natural gas is approx. six times more expensive to transport than oil on an energy equivalent basis.

- the price of oil in Canada is determined by international supply and demand factors (beyond Canada's control) while the price of natural gas in Canada reflects demand (domestic and export) and the incremental costs of making it available.

- long lead times are required for marketing and transportation arrangements, regulatory approvals, financing and the construction of facilities for oil and gas development in northern and offshore areas (in the order of 8 to 10 years).

- energy pricing policies and export controls have had a significant negative impact on the Canadian economy.

- conflicts between objectives of resource development and revenue sharing were important factors behind the more contentious elements of the NEP.

- major structural changes in the Canadian economy reflecting world-wide environmental concerns could lead to much greater gains in energy use efficiency and conservation.

- the "abiogenetic" theory of natural gas origin, if true could mean a natural gas based economy is possible as oil production declines.

- frontier gas production in Canada will likely be required by the year 2000.

Appendix B - FUEL PRICE EQUATIONS AND DEMAND EQUATIONS COEFFICIENTS

DEMAND EQUATIONS AND PRICE EQUATIONS

A generalized, fuel price equation was assumed to have a form:

Fuel Price = a + b (Crude Oil Price, \$/bbl)

and

Petrochemicals Price = a + b (Natural Gas Price, \$/GJ)

The constants were regressed from retail or chemical commodity price data for 1972 to 1987 Canadian prices. The coefficients are listed in Table B1. In the demand model we use CERI's coefficients for fuel prices and Lobbe's coefficients for petrochemical prices.

The coefficients b, c and d for the demand equation model are listed in Table B2. They were somewhat adjusted from those reported by CERI (1988), to reflect scenarios's environmental and technological factors.

Table B1. PRODUCT PRICE VS FEED COST RELATIONSHIP

	CONSTANT a	CONSTANT b	R^2
CERI[1]			
Gasoline	15.00	2.00	0.95
Middle Distillates	12.50	1.75	0.90
Heavy Fuel Oil	2.75	1.25	0.90
Other	30.00	2.00	na
LOBBE[2]			
Gasoline[3] (Canada)	13.08	1.82	0.88
Gasoline[4] (Montreal)	11.40	1.66	0.66
Methanol[5]	9.0	4.6	0.81
Ethylene[6]	99.7	95.5	0.89
Benzene[7]	15.8	11.4	0.78

[1] Fuel Price, \$/bbl = a + b(\$OIL/bbl), CERI (1988)

[2] based on 1972-1987 Canadian retail prices

[3] \$CDN/bbl Edmonton, average Canadian gasoline prices

[4] \$CDN/bbl Montreal Import, average Quebec gasoline prices

[5] ¢/L = a + b (\$/GJ) average industrial prices

[6] \$/tonne = a + b (\$/GJ) average industrial prices

[7] \$/tonne, Oil \$/bbl

Table B2. DEMAND EQUATIONS COEFFICIENTS

COMMODITY	b	c	d
Gasoline	- 0.125	0.200	0.300
Middle Distillates	- 0.225	0.400	0.300
Heavy Fuel Oil	- 0.350	0.200	0.500
Other	-0.125	0.250	0.600

Source: CERI (1988)
Lobbe Technologies Ltd.

Appendix C - ORGANIZATIONAL AND MANAGMENT FACTORS IN R&D PLANNING

ISSUES RELEVANT TO R&D PLANNING:
ORGANIZATIONAL AND MANAGEMENT FACTORS

Modern R&D management theory recognizes that research and development activities are not limited to carrying out specific tasks or meeting specific targets, but that R&D constitutes a process which changes with the growth and maturity of the project. The process is viewed today as continuous, as opposed to the traditional division of R&D activities into research, development, demonstration and transfer stages (Figure C1). The emphasis is on fostering interaction between different organizational groups to counteract any discontinuity that may arise during the transfer of the project, as it matures, from group to group.

Despite the above, the actual management of R&D projects still addresses the different stages of the R&D process. The reason for the adherence to a staged (phased) approach is that each phase of the R&D process imposes different requirements on human resources, facilities, capital and management techniques, and because such resources are placed within different groups in most business and government organizations (Figure C2). Another reason why the R&D process is treated as partitioned is the fact that as the project progresses, the commitment of resources often increases by several orders of magnitude and the type and detail of management required (budgeting, level of evaluation, project control and risk assessment) becomes more extensive. It may be

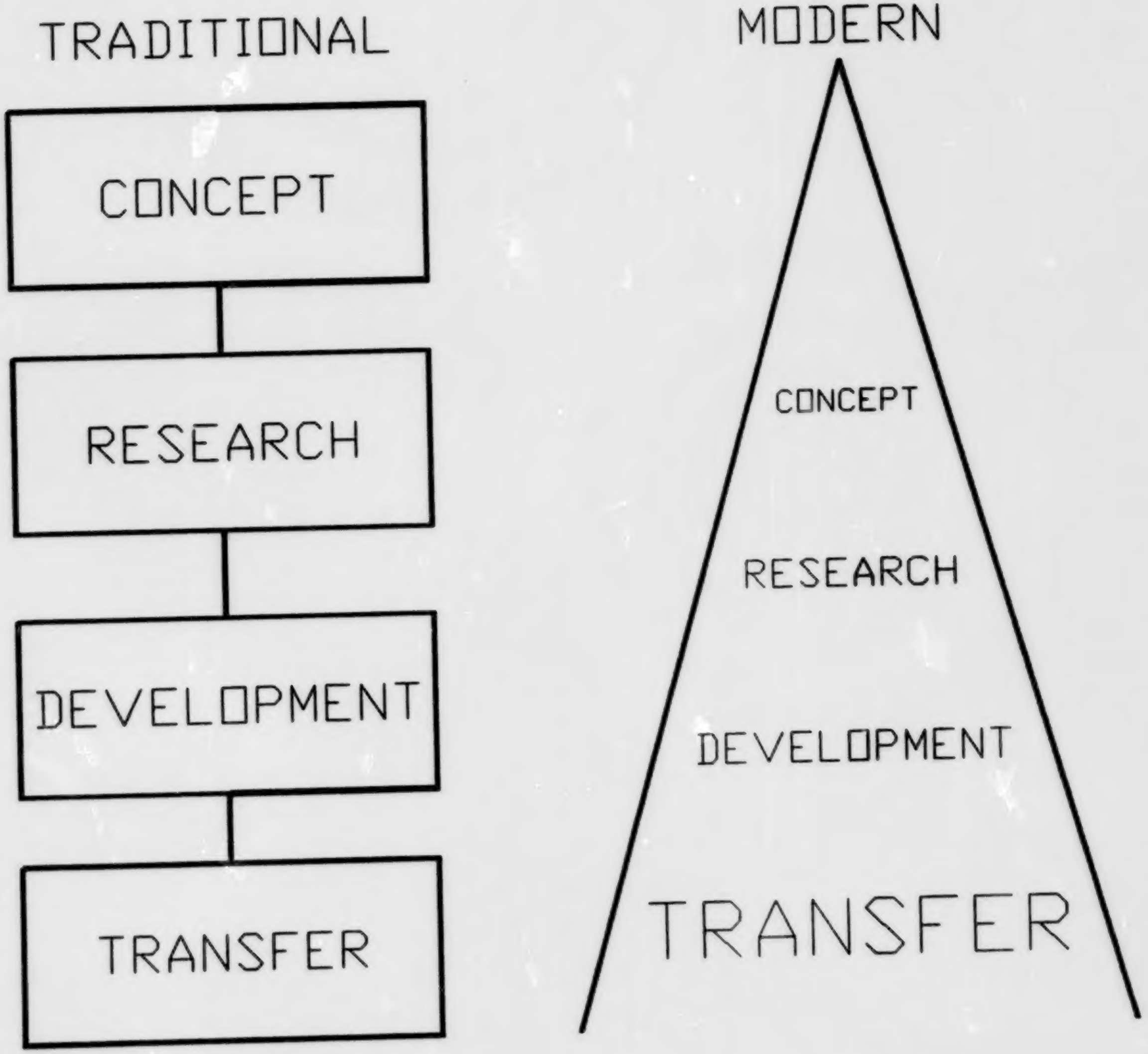

Figure C1. SCHEMATIC REPRESENTATION OF R&D PHASES

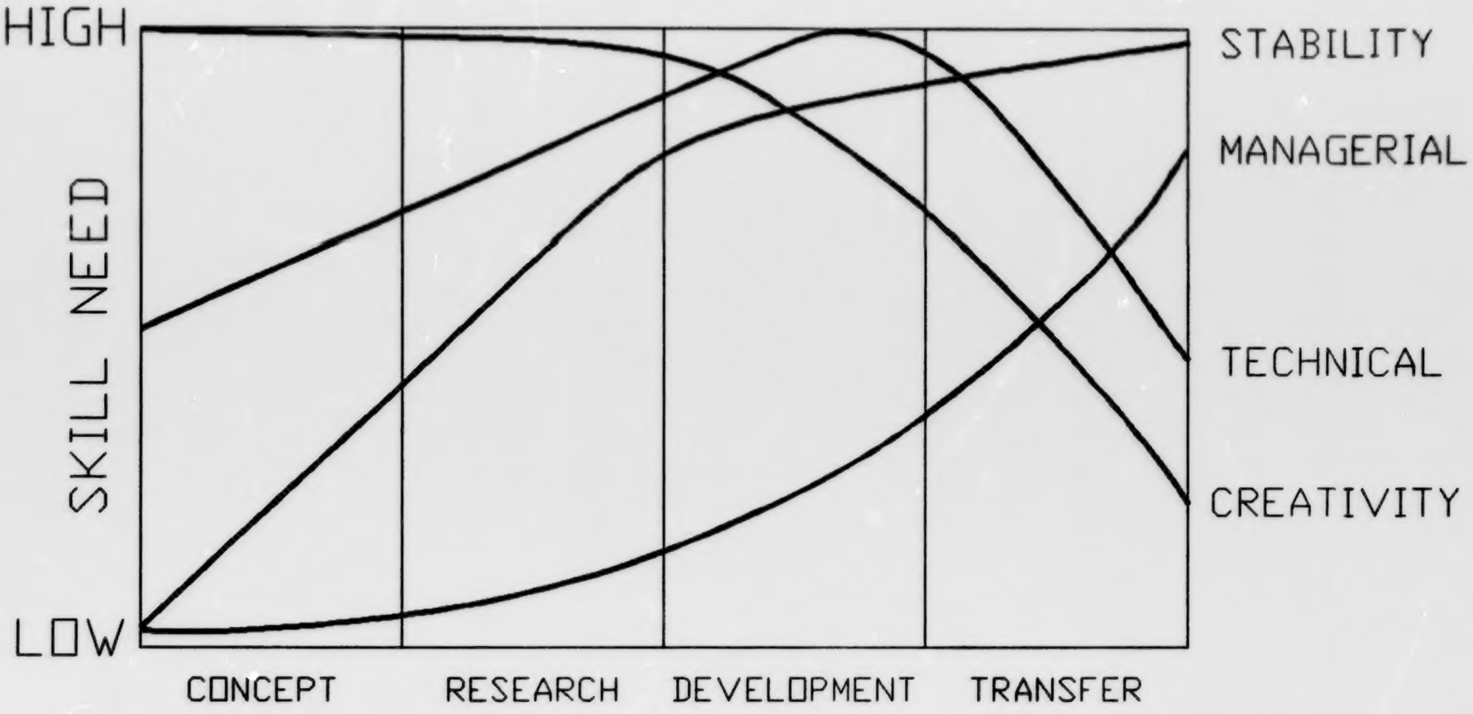

Figure C2. SKILLS AND RESOURCES NEEDED AT DIFFERENT R&D PHASES

convenient, for example, to proceed with exploratory research based on a sketchy definition of markets and business environment, but the demonstration phase of a large R&D development would definitely require a detailed evaluation of all aspects of the technology, business markets, regulatory issues and environmental concerns. It is practical, therefore, to treat the R&D process as consisting of broadly defined stages, each with different appraisal methods.

R&D projects must also be evaluated within the constraints of an organization's R&D portfolio. The concept of an R&D portfolio is analogous to a business portfolio, which underscores the importance of diversity and risk "spreading" when the goal is to maximize the return on expended capital. A typical R&D portfolio could include several projects in strategic, tactical and service oriented research. Another type of R&D portfolio may include near-term, mid-term and long-term research projects defined in relationship to the objectives of the organization or business.

Issues relevant to the planning of R&D projects will, therefore, include a number of considerations. First, each project should be appraised using methods appropriate for the particular stage of the project. Second, each project should be considered within the constraints of the organization's R&D portfolio, i.e. a strategic mix of projects should be maintained, alternative programs for achieving objectives should be identified. And third, the various projects and alternatives should be ranked with respect to the selection criteria broadly classified into:

1. Strategic Factors: Typically includes a checklist which defines organizational, program or business goals (Table C1). A "strategic factors" approach is most suitable for the appraisal and planning of new projects, or for planning long-term research at the conceptual stage.
2. Profitability Measures: Includes a project's financial measures such as benefit/cost ratio, net present worth, payback period, return on investment (discounted), rate of return (discounted), etc.
3. Risk Assessment: Includes an assessment of probable market prices and may utilize methods such as Monte Carlo Simulation, Experience Curve, Decision Tree, Utility Function, etc.

The manner in which the above criteria are applied will differ for each stage of the project. The extent of the evaluation will vary depending on the amount of resources being requested for the project (Table C1). Also, the hurdle rate or the appraisal target value will depend on the type of the R&D project. For example, for strategic projects a benefit/cost ratio larger than 10 to 15 would likely be expected, whereas for service research, ratios as low as 3 to 5 might be accepted.

To assist with the appraisal and screening of new projects strategic factors can be considered through the use of an R&D checklist. R&D checklists are usually constructed based on:

1. a strategic view of the future (scenario planning and forecasting);
2) market research; and
3) business or organizational goals.

Table C1. TYPICAL APPRAISAL METHODS FOR R&D PROJECTS

R&D PHASE	PERFORMER	PROJECT APPRAISAL AND EVALUATION METHODS	
CONCEPT	Anywhere inside or outside organization	Strategic Factors:	checklist
		Portfolio Planning:	broadly defined objectives, rewards & risk
		Profitability Measures:	benefit/cost ratio, present worth, payback, return on investment
RESEARCH	R&D department	Strategic Factors:	checklist
		Portfolio Planning:	focused objectives, defined rewards and risks, zero-based budgeting
		Profitability Measures:	benefit/cost ratio, present worth, payback, return on investment, rate of return (discounted)
DEVELOPMENT	R&D, Engineering	Profitability Measures:	present worth, payback, rate of return, etc.
		Risk Assessment:	sensitivity analysis
TRANSFER	Marketing, Engineering, Operations	Market Research:	market profile, etc.
		Profitability Measure:	as in Development
		Risk Assessment:	sensitivity analysis, Monte Carlo Simulation, Experience Curve, Decision Tree Method, Utility Function

A checklist may address issues such as increased profitability, reduction of costs, enhancement of present business activities, diversification into new business areas etc. (Table C2). A checklist can be applied in project screening or appraisal by a process of requiring simple Yes or No answers. Projects which meet all or majority of the listed criteria would usually be eligible for funding. If R&D portfolio planning is used, the approved project would still have to be ranked against other R&D projects or services.

It follows from the above discussion that an R&D checklist could be used for screening and appraising R&D projects on the conversion of natural gas to transportation fuels or fuel components. To be appropriate and effective within the confines of this study, the R&D checklist should include an explicit set of selection criteria that can be used to assess an R&D projects in the light of the opportunities, constraints and critical factors for natural gas R&D conversion, identified in each of the scenarios analyzed.

Table C2. EXAMPLE OF A SIMPLE R&D CHECKLIST

SERVICE COMPANY XYZ INC.

Does the proposed R&D project:

1. optimize XYZ in some operational aspect?
   (i.e. reduce operating cost)
2. enhance safety/environment at XYZ Inc.?
3. result in better service to customers?
4. introduce important new knowledge/technology to XYZ Inc.?
5. develop new markets for XYZ Inc.?

Appendix D - HOI CRUDE OIL DEMAND

Appendix E - HRD CRUDE OIL DEMAND

Appendix F - GREENHOUSE GASES EMISSIONS

Greenhouse Gases From Fossil Fuel Burning

In 1987, Canada used 1117.8 PJ of coal, 3155 PJ of crude oil and 2358 PJ of natural gas. Assuming combustion efficiencies of 98 percent for coal, 95 percent for crude oil and 98 percent for natural gas, the total carbon dioxide emission would be 422.5 megatonne per year (Table F1).

The transportation sector used 1698 PJ, assuming an average weighted combustion efficiency of 95 percent this would yield 116.7 MT/Y of carbon dioxide or 27.9 percent of total Canadian CO_2 emissions.

Table F1. CARBON DIOXIDE PRODUCED BY BURNING FOSSIL FUELS IN CANADA

FUEL	CONSUMED PJ/Y	MT/Y	% CARBON	% BURNED	CO_2 FORMED MT/Y
COAL	1,117.8	50.5	55.9	98	101.4
CRUDE OIL	3,155.3	67.2	85.0	95	199.0
NATURAL GAS	2,358.5	42.8	74.5	98	114.6
TOTAL					422.5
TRANSPORTATION SECTOR TOTAL	1,698.7	39.1	86.5	95	117.8
HIGHWAY AND AVIATION	1,338.0	34.2	86.5	95	103.0

Greenhouse Gases From Transportation Fuels (Baseline)

In 1987, the Canadian transportation sector used 1043 PJ of motor gasoline, 345 PJ of diesel fuel, 141 PJ of aviation fuel, 49 PJ of HFO and 119 PJ of natural gas or NGL. Since gasoline and diesel constitute a majority (over 92 percent) of total transportation sector energy use, we will consider only highway transportation sector in terms of greenhouse gases emission. The transportation sector CO_2 emission is on the order of 27.9 percent of the total Canadian (Table F1).

CO_2 From End Use:

The total highway and aviation energy use was 1388 PJ. Assuming a weighted carbon content of the fuels 86.5 percent, 95 percent combustion efficiency, the total carbon dioxide emission would be 103.0 megatonne per year (MT/Y).

CO_2 From Fuel Production and Distribution

An average efficiency of processing, refining and transporting gasoline and diesel fuel is about 86 percent. Some of the energy loss in production and transportation is not in the form of carbon dioxide. We assume that 90 percent of energy lost is in combustion of fuel or otherwise converted to carbon dioxide. The carbon dioxide emission from refinery production and transmission would be then 12.6 percent or 12.8 MT/Y.

N_2O Emissions From Refineries

About 0.028 kt of N_2O is generated per one petajoule of oil burned (HaO et al., 1987). This would be equivalent to 1.0 MT/Y of CO_2, assuming 12.6 percent of refinery energy input is burned and using an N_2O/CO_2 conversion factor of 175.

Methane From Natural Gas Co-produced with Petroleum

The energy waste with coproduction of petroleum is about 0.5 to 1 percent (EIA, 1987). We estimate, therefore, that 8.1 PJ would be associated with CH4 losses during crude oil production. Since most of this methane would be burned, the amount of carbon dioxide would be 0.4 MT/Y.

Total CO_2 - Equivalent emission from gasoline and diesel vehicle would be:

CO_2 from end-use	103.0
CO_2 from fuel production and distribution	12.8
CO_2 equivalent from N2O generated	1.0
CH4 from venting	0.4
TOTAL	117.2

GREENHOUSE GASES FROM BITUMEN

CO_2 From End-Use (vehicles)

It is assumed that transportation fuels derived from bitumen would have efficiency similar to that from petroleum derived fuels. The total end-use emission would be 103.0 MT/Y.

CO_2 From Gasoline And Diesel Production And Distribution Using Synthetic Crude

Again, the amount of carbon dioxide produced would be equivalent to emission from petroleum, i.e. 12.8 MT/Y.

CO_2 From Upgrading of Bitumen to Synthetic Crude

The energy efficiency of bitumen upgrading is estimated at 67.5 percent plus 7 percent for coke and sulphur energy credits (total 74.5 percent). The remaining energy is assumed to be converted to carbon dioxide at 96 percent efficiency. Also, a part of the energy input (about 6 percent) is assumed to come form the use of natural gas (similar to Syncrude operations). The amount of CO_2 generated would be 22.0 MT/Y from bitumen and 5.4 MT/Y from natural gas for a total of 27.4 MT/Y.

CO_2 Generated During Bitumen Production (In-Situ)

Burger (1979) estimated the energy required for in-situ exploitation of heavy oil and bitumen at 13 percent plus for in-situ combustion and 30 percent plus for steam injection. We assume a 25 percent of output energy required for bitumen product or 466 PJ. The amount of carbon dioxide generated would be then 22.6 MT/Y, assuming natural gas being burned for in-situ bitumen production.

N_2O Emissions From Refineries

Similar to crude oil, synthetic crude is assumed to generate about 1.0 MT CO_2 equivalent per year.

TOTAL CO_2 - equivalent emissions would be:

CO_2 from transportation end-use	103.0
CO_2 from fuel production	12.8
CO_2 from synthetic crude production	27.4
CO_2 from bitumen production	22.6
N_2O emissions from refineries	1.0
	166.8

GREENHOUSE GASES FROM NATURAL GAS LIQUIDS (NGL)

In 1987 Canada produced 6.2 x $10^6 m^3$ of pentanes plus, 5.9 x $10^6 m^3$ of propane and 3.3 x 10^6 m^3 butanes. About one third of that production was exported and the rest was used by residential, transport and industrial sectors (CPA, 1988). NEB (1988) projects a continued supply of pentanes plus (20 Mm^3/d), butanes (15 Mm^3/d) and propanes (25 Mm^3/d) which could become a source of transportation fuels. The calculations below show the amount of carbon dioxide or greenhouse gas equivalent that would result from the application of propane.

CO_2 From End Use of Propane

The information on performance of natural gas and propane engines indicates that 1388 PJ of transportation fuel could be replaced with 1243 PJ of propane, due to higher vehicle efficiency (10% better). We assume a further increase of efficiency due to 97 percent of carbon combustion. If propane replaced all gasoline and diesel fuel, then the amount of carbon dioxide generated would be 68.6 MT/Y.

CO_2 Emissions From Production and Distribution of NGL (propane)

Energy balance around the oil absorption process indicates 1.2 percent energy loss around the absorber (Handbook of Natural Gas Engineering, 1959). Including energy use in distribution, we assume 2.4 percent energy required for prediction and distribution of propane. Since most of it would be based on combustion of natural gas, the associated carbon dioxide release would be 1.5 MT/Y.

CO_2 Emissions From the Compression and Storage of NGL's

Data indicate 2 to 4 percent energy required for compression of natural gas to CNG. For NGL's we assume 0.5 percent of electrical energy required for service. Since production of electrical energy is about 30 percent, the energy required would be 1.7 percent or 21 PJ/y. Assuming that electrical energy comes from coal fired power plants, the amount of carbon dioxide would be equal to 1.9 MT/Y.

Hydrocarbon Emissions Loss from Distribution of NGL's

We assume a 2.5 percent loss of hydrocarbons from storage and distribution, and CH/CO_2 conversion factor of fifteen. The amount of carbon dioxide would then be 26.5 MT/Y.

Total CO_2 - equivalent emissions for propane vehicles would be:

CO_2 from end-use	68.6
CO_2 from production and distribution	1.5
CO_2 from compression and storage	1.9
CH_x from distribution and storage	26.5
TOTAL	98.5

Volume

2

Report

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ASSESSMENT OF NEW TECHNOLOGIES FOR NATURAL GAS CONVERSION USING SCENARIO ANALYSIS

VOLUME II

Prepared by

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MAJOR CONSTRAINTS ASSOCIATED WITH EXPLOITATION OF RESOURCES

1.0. NATURAL GAS

Canadian conventional reserves of natural gas are declining and by the year 1999 frontier production will be required (NEB, 1988). In the interim, the rate of reserve addition from conventional production areas will be constrained primarily by market prices for natural gas (Table 1).

1.1. Technological Constraints

We have not identified any major technological constraints on the exploitation of conventional gas reserves. However, technological advances can be expected to maintain or reduce exploration and production costs, therefore, allowing smaller and more isolated reserves to be developed in a financially viable manner.

With respect to frontier gas reserves, the Canadian east coast and Arctic regions are different enough from the rest of the world to necessitate the use of unique offshore exploration and production technology.

For gas from both new conventional areas and frontier areas, gathering and transmission pipeline facilities must be in place before reserves can be exploited. Figure 1 depicts the Canadian

Table 1. CANADIAN ENERGY RESERVES (1987)

	CRUDE OIL[1] million cubic metres			NATURAL GAS[1] billion cubic metres		COAL million tonnes			ELECTRIC GENERATION CAPACITY[2] megawatts			
AREAS	CON.	FRONT.	BIT.	CON.	FRONT.	BIT.	SUB.	LIG.	HYDRO	COAL	NUC.	GAS
NEWFOUNDLAND AND PEI	-	-	-	-	-	-	-	-	6560	576	-	304
NOVA SCOTIA	-	-	-	-	-	445	-	-	384	1783	-	206
NEW BRUNSWICK	-	-	-	-	-	18	-	-	903	1868	680	28
QUEBEC	-	-	-	-	-	-	-	-	24928	638	951	473
ONTARIO	0.8	-	-	13.2	-	-	-	-	7172	13101	9033	628
MANITOBA	9.6	-	-	-	-	-	-	-	3641	446	-	54
SASKATCHEWAN	110.1	-	-	50.3	-	-	-	1697	576	1957	-	162
ALBERTA	566.4	-	10750.0	1760.2	-	526	918	-	734	5916	-	570
BRITISH COLUMBIA	18.6	-	-	246.2	-	2098	-	566	10852	1352	-	94
YUKON & NWT	35.2	-	-	10.6	-	-	-	-	131	-	-	168
FRONTIER[3]												
Nova Scotia Offshore		29.9			160.9							
Mainland Territories		37.2			20.8							
MacKenzie Delta & Beaufort Sea		253.2			302.1							
Arctic Islands & Eastern Arctic Offshore		65.7			416.4							
Grand Bank & Labrador Sea		181.0			146.8							

[1] Remaining established reserves
SOURCE: NEB Report, October 1986

[2] SOURCE: CPA Statistical Handbook For 1987

[3] SOURCE: The Canada Oil and Gas Lands Administration: Annual Reports For 1983-1987

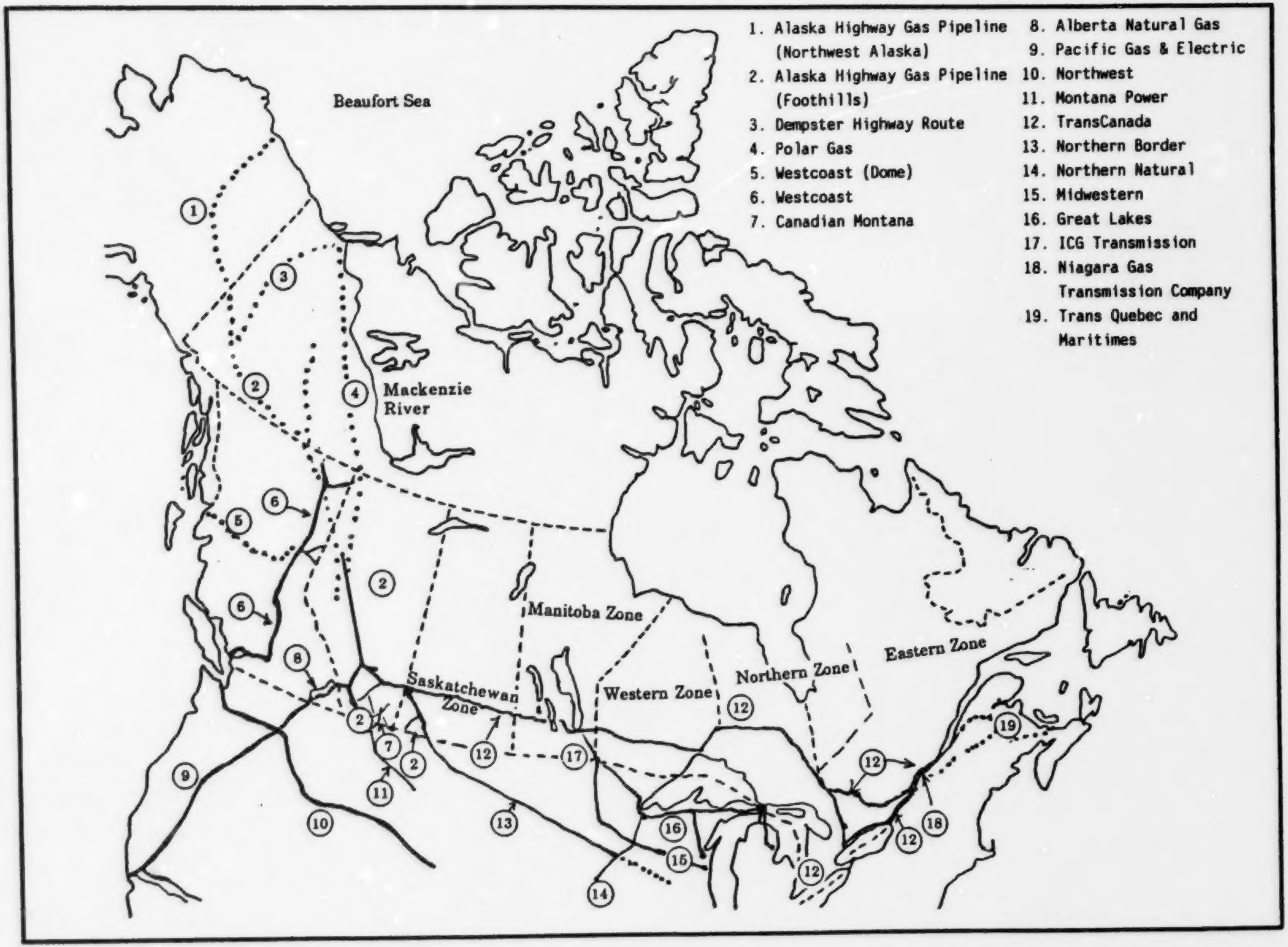

Figure 1. THE CANADIAN PIPELINE NETWORK

pipeline network for natural gas. The lack of pipeline facilities from new production areas is a possible constraint. Exploration successes and size of reserves will dictate when, or if, transportation systems can be built to large reserves in isolated areas or to smaller reserves in conventional areas.

In addition to the conventional and frontier gas reserves, unconventional gas reserves occur in very low permeability (so-called "tight") reserves in west-central Alberta and north-eastern British Columbia. There is little history of production from these reserves and it is not known how much of the resource may be technically recoverable, but this resource may in future make a substantial contribution to the western Canadian gas supply (NEB, 1988).

1.2. Environmental Constraints

In the conventional production areas, environmental considerations associated with the exploration, drilling, production and transmission of natural gas do not yield any significant constraints. The environmental safeguard practices associated with the exploration and development of conventional reserves are well established. The removal of sulphur oxide from sour gas, for example, represents a hazard because of the blowout risk. However, technology exists to allow the economic production of gas and sulphur from such wells.

Northern Canada, particularly the Arctic regions, has a unique and delicate ecosystem. Exploration of gas reserves in these areas will require compliance with much more rigorous environmental restrictions than is the case in southern Canada.

It can be expected that environmental regulations required in northern Canada and in the East Cost offshore areas will add significantly not only to the cost of gas from these areas but also to the time required to obtain the necessary approvals to proceed with the exploitation of the reserves.

1.3. Political Constraints

Table 2 outlines the major Canadian and U.S. policies that affected natural gas (and oil) from 1957 through to 1987.

The regulatory activities of both the federal and the provincial governments can be perceived as constraints on the development of new reserves primarily because of the uncertainty that past actions have created in the market place. For example, during the last 15 years export markets to the U.S. went through a transition from essentially a free market to a system rigidly controlled by government policy back to a free market environment.

Regulatory decisions can also significantly alter the economics of a project. For frontier areas which may have lead times of up to 8 years for project development any uncertainty about

Table 2. MAJOR CANADIAN AND U.S. POLICIES AFFECTING NATURAL GAS AND OIL

1957	Borden Royal Commission on Energy established.
1959	Report of the Borden Royal Commission on Energy published.
	National Energy Board (NEB) established under the National Energy Board Act with power to license pipelines crossing provincial boundaries, as well as petroleum and natural gas imports and exports.
1961	National Oil Policy (NOP) introduced: area west of the Ottawa Valley reserved for Canadian crude oil. Area to east dependent on imported oil.
1970	Mandatory controls on gasoline imports introduced, lasting until October 1973.
1971	First disapproval of an energy export by the NEB. Export surplus test for natural gas of reserves sufficient to meet 25 times the Canadian annual demand introduced.
1973	NOP terminated. Government announces 60 day freeze on the price of Canadian produced crude oil. Government controls on the price of crude oil at the well head and on the prices of the petroleum products begins and extends to June 1985. Export tax on crude oil also introduced.
1974	Oil Import Compensation Program introduced in order to subsidize the cost of imported crude oil and products. Light oil exports to U.S. to be completely phased out by 1982.
1975	Petroleum Administration Act, an umbrella regulatory act, (subsequently called the Energy Administration Act) introduced. Gave the federal government the power to set the price of crude oil and natural gas with or without provincial approval. "Made in Canada" oil price was held below world oil prices.
	First Canada/Alberta Gas Pricing Agreement effective Nov. 1, 1975.
	Price for Alberta natural gas sold in interprovincial trade at levels agreed to by Alberta and federal government from 1975 to 1985.

Table 2. MAJOR CANADIAN AND U.S. POLICIES AFFECTING NATURAL GAS AND OIL (cont'd)

1977	NEB announces more rapid phase-out of light oil exports to the U.S. but an increase in heavy oil exports.
1978	U.S. Natural Gas Policy Act passed. Increases the price for "new" gas in the U.S. U.S. Fuel Use Act prevents oil and gas from being used in large industrial boilers and prohibits the construction of new gas-fired electrical generation plants.
1979	Growing supplies of natural gas creates demand for increased exports, NEB allows additional short-term exports (maximum 5 year contracts).
1980	National Energy Program (NEP) introduced with three objectives: 1) security of supply through independence from the international market; 2) increased Canadianization of the industry through domestic ownership; and 3) fairness in the determination of prices and allocation of revenues. Policies of the NEP included: 1) A federally imposed schedule providing for a gradual increase in the domestic price of oil towards the international price. 2) The Petroleum and Gas Revenue Tax. 3) The Petroleum Compensation Charge. 4) The Canadian Ownership Special Charge. 5) Incentives to encourage consumers to substitute away from oil and to conserve energy. 6) Direct subsidies for exploration and development activity, the Petroleum Incentive Payment, to replace depletion and super-depletion allowances. Preferential treatment is given to firms based on their degree of Canadian ownership, and to exploration offshore and in the Territories (Canadian lands). 7) Provision for Petro-Canada to purchase one or more large subsidiaries of foreign petroleum companies with assistance from the Canadian Ownership Special Charge.

Table 2. MAJOR CANADIAN AND U.S. POLICIES AFFECTING NATURAL GAS AND OIL (cont'd)

	8) Reservation for the Crown of a 25 percent interest in development on Crown lands, including discoveries prior to 1980 (the back-in provision).
1981	Agreement reached between the federal and Alberta governments for a schedule of oil price increases.
1983	Growing excess supplies of oil and gas in western Canada. NEB allows increasing export volumes as well as decreasing export prices for natural gas.
1984	The U.S. Economic Regulatory Administration (ERA) issues new policy which allows import arrangements for natural gas to be freely negotiated between buyers and sellers.
	The U.S. Federal Energy Regulatory Commission (FERC) issues Order 380 which prohibits pipelines from passing on to their customers take-or-pay charges. Effectively increases investor risk for financing new gas supplies including Canadian.
1985	The Atlantic Accord between the federal government and the government of Newfoundland creates an equal partnership in the development of offshore resources.
	The Western Accord between the federal government and those of the three western provinces to remove crude oil price controls, to allow the price to follow world prices from June 1, 1985 and to allow the immediate or phased removal of various energy taxes and levies, effectively abolishing the NEP.
	The U.S. Natural Gas Policy Act is used to deregulate approximately 60 percent of U.S. gas production ("new gas").
	FERC Order 436 encourages interstate pipelines to move towards "open access" natural gas transportation. Also encourages U.S. gas production at the expense of Canadian imports.
1986	FERC Opinion 256 prevents Canadian gas producers from passing on fixed transportation demand charges to U.S. buyers. Inflates commodity cost of Canadian gas vs. U.S. supplies as demand charge is absorbed as part of commodity cost.

Table 2. MAJOR CANADIAN AND U.S. POLICIES AFFECTING NATURAL GAS AND OIL (cont'd)

	FERC Order 457 sets new higher single price for U.S. "old" gas. Increases supply of U.S. gas and lowers price for all gas in U.S. including gas imported from Canada.
	NEB first revises export surplus test to reserves to production level of 15 years and then removes export surplus test completely.
1987	FERC Order 500 improves acceptability of "open access" operation to pipelines and the majority of U.S. interstate pipelines become "open access".

government regulations and policy decisions will pose significant constraints on the development of reserves. For example, Esso Resources Canada Ltd. and Shell Canada Ltd. recently filed an application with the National Energy Board for licences to export natural gas from the MacKenzie delta to the United States. The licenses would be for a period of 20 years beginning November, 1996. Thus the investment decisions these companies consider today will encompass an economic life span of the project until the year 2116. A review of Table 2, which also covers a 20 year time span, clearly demonstrates the magnitude of potential policy changes that either Canadian or U.S. governments could implement detrimental to a frontier export natural gas project.

Within Canada, the fiscal systems affecting the gas industry over the last two decades have, for the most part, been a sequence of changing tax systems. Tax and royalty regimes have been substantially adjusted, both up and down, and continue to be adjusted on a frequent basis in response to prevailing conditions in world energy markets or as a result of government policy decisions.

Also within Canada, the producing provinces and the consuming provinces have different interests when it comes to the question of access to and pricing for an energy commodity such as natural gas. This often leads to differing policies at the provincial and federal levels. For example, concurrent with the deregulation of gas prices and greater access to transportation facilities which is endorsed by the federal government and the consuming provinces, we have the introduction of unilateral "floor" pricing by Alberta, i.e., the introduction of volume units and different pricing for "core" and "non-core" markets.

1.4. Social/Economic Constraints

In the northern areas of Canada there are indigenous cultures still pursuing traditional lifestyles. Projects in which energy resources are exported from these areas are often seen by the Native people as a threat to their land-based economy. Development of reserves in these areas will require special attention to the social and economic effects on the lifestyles and culture of the native people. The costs of some aspects of development in northern areas, such as land claim settlements will be borne by the federal government. However, for producers in these areas, there are project-specific costs such as those due to lengthy delays associated with land claim settlements, or costs resulting from special employment requirements.

In some cases projects have been delayed indefinitely as a result of land claims and environment reviews. For example, the MacKenzie Valley Pipeline inquiry ran for almost two years and the result was an imposition in 1977 of a ten-year moratorium on any pipeline developments within the valley. The Alaska Highway Gas Pipeline project suffered a similar fate. Review processes and land claims issues helped to delay the project from the initial stages of development in 1976 until it was finally shelved in 1983. By 1983 the cost estimates had escalated significantly because of very high interest rates during that time-frame and the surplus of gas that had developed in U.S. markets.

For both conventional and frontier areas, pricing, or more correctly price expectations, will determine the rate of development and exploitation of reserves. For example, significant additions to reserves occurred during the last 15 years in response to dramatic increases in world oil prices in 1973 and 1978 (Table 3). The subsequent fall of world oil prices, and the general supply/demand imbalance caused in part by a recession in the early 1980's, resulted in a falling off in the rate of reserve addition. Whatever factors establish price expectations, the current market uncertainty is a constraint to the development of new reserves, particularly in frontier areas. Table 4 depicts estimated wellhead price and transportation cost for Arctic and offshore reserves of natural gas.

Table 3. RESERVES ADDITION FOR CANADA

YEAR	CRUDE OIL, million m^3		NATURAL GAS billion m^3	ELECTRICITY megawatts
	CONVEN.	BIT/SYNTH[1]	CONVEN.	
1965	79.2	-	127.1	
1966	142.5	-	33.5	
1967	61.5	-	131.3	
1968	86.1	1009	80.5	
1969	3.1	-	183.6	
1970	0.0	-	61.9	
1971	33.8	-	152.5	
1972	7.9	-	26.5	
1973	3.4	-	111.7	3144
1974	10.8	-	47.1	3828
1975	11.6	-748	49.5	4646
1976	12.7	-	138.2	4582
1977	21.1	-	169.7	3935
1978	25.4	-	217.8	2720
1979	21.2	8	132.3	4772
1980	2.4	-	85.2	1747
1981	37.7	-	194.8	1801
1982	52.0	-	91.3	3980
1983	46.8	-	36.0	5697
1984	83.5	68	40.2	1795
1985	43.4	-	51.7	
1986	49.4	-	34.2	

[1] SOURCE: CPA Statistical Handbook For 1987

SOURCE: NEB, 1986,1987

Table 4. ESTIMATED COST OF NATURAL GAS FROM FRONTIER AND OFFSHORE AREAS ($1988)

RESOURCE	WELLHEAD PRICE $ / GJ	TRANSPORTATION COST $ / GJ
MACKENZIE DELTA AND BEAUFORT SEA	2.50 - 3.50[1]	1.40 - 2.80[2]
EASTERN OFFSHORE	4.50[3]	-

[1] NEB (1988)

[2] CERI (1988)

[3] delivered, CERI (1988)

2.0. OIL

Exploration in Canada's conventional oil producing areas is mature and approximately 85 percent of the original conventional oil has been discovered. However only one-third of the original resource base is recoverable (NEB, 1986) (Table 1).

Exploration in Canada's frontier areas is new and approximately 10 percent of the estimated resource base has been discovered (NEB, 1986).

The development of bitumen and heavy oil is currently technically feasible but the technology is expensive. With dramatically fluctuating world oil prices, the economics of recovery are still very uncertain.

2.1. Technological Constraints

Of the estimated over 3300 million cubic metres of conventional reserves in place in the Western Sedimentary Basin, only 20 percent of the light/medium crude and 10 percent of the heavy crude oil can be recovered by primary recovery. An additional 10 percent of each of the light/medium and heavy oil reserves is estimated to be recoverable through secondary and tertiary recovery with current techniques. The total conventional crude oil reserves are estimated at about 960 million cubic metres (NEB, 1988). Therefore, advances in enhanced oil recovery technology could provide access to significant additional crude oil production from Canada's conventional reserves.

Conventional oil accounts for less than 10 percent of Canada's ultimate technically recoverable resources, whereas bitumen accounts for over 90 percent of Canada's ultimate resources of crude oil (NEB, 1988). Since reserve additions of conventional oil (Table 3) are insufficient to meet current production levels of about 70 million cubic metres per year (CPA, 1988), additional oil will increasingly be required from bitumen reserves and/or offshore purchases. However, given current and projected low prices for crude oil on the world markets, technological breakthroughs will be required in the technology of mining and processing of oil sands before development and exploration of these reserves can occur on a larger scale.

In-situ processes for the extraction of heavy oil via steam injection are more likely to be used than oil sands mining and processing because: 1) current technology can be deployed on smaller scale projects therefore making the financial risk lower; and 2) there are growing markets in the U.S. for heavy crude oil which can be sold without first being upgraded to synthetic crude.

As in the case of natural gas reserves, technological advances can be expected to maintain or reduce exploration and production costs for crude oil, which would allow smaller discoveries to be brought into production in conventional areas.

To date, only minor production of crude oil has taken place in the Arctic frontier area (1.5 million cubic metres in 1986) (CPA, 1988). Developments in the Arctic and the East Coast offshore face significant technological barriers due to geography, ocean drilling and severe climatic conditions. Developments in the frontier areas will be expensive and economic recovery of these resources will be very sensitive to reservoir size and production capacity (Table 5). As in the case of gas reserves, exploration successes and size of reserves will dictate when, or if, transportation systems can be built to access remote reserves or isolated, smaller reserves in conventional areas.

2.2. Environmental Constraints

The environmental safeguard practices associated with the exploration and development of conventional reserves are well established. However, the massive scale of bitumen mining and oil sands processing presents unique environmental problems with respect to the amount of water required to process the sands, the disposal of tailings and sulphur emissions (Table 6).

Environmental restrictions in northern Canada and in the East Coast offshore will be very stringent. The ability of the ecology to withstand oil contamination, whether through accidental spills or discharges during production, is very limited. The disposal of any waste products in these environments poses significant problems. In addition,

Table 5. ESTIMATED COST OF CRUDE OIL FROM FRONTIER RESOURCES AND BITUMEN

RESOURCE	SUPPLY COST $ / bbl
NOVA SCOTIA OFFSHORE	19(21)[1] - 29(32)
MACKENZIE DELTA AND BEAUFORT SEA	23(25)
TAR SANDS	
In-situ	27(31)
Mining	27(36)

[1] Field that can be developed with floating production platform: $19/bbl at 10 percent discount on investment; ($21) at 15 percent discount on investment.

SOURCE: NEB (1988)

Table 6. ENVIRONMENTAL CONSIDERATIONS IN IN-SITU BITUMEN PRODUCTION

IMPACT	IMPACT ASSESSMENT	MITIGATION TECHNOLOGIES
Product Water	Produced water contains high levels of dissolved solids, suspended and dissolved oil, and small levels of H_2S, silice, heavy metals, etc.	Water treatment, recycling and disposal (lime treatment or ion exchange).
Solid Waste		
Lime Sludge	Spent lime sludge is generated as a waste by-product of the produced water treatment plant.	Use of spent lime sludge for agricultural land by land spreading. Landfill site.
Oily Solids	A combination of oiled clays, sand and organic debris is generated during bitumen production.	Use of oil produced sand for road improvement.
Drilling Fluid	Drilling of in-situ wells results in a requirement to dispose of drilling fluids.	Drilling fluids would be disposed by floculation of suspended solids The decanted saline fluids to be disposed of via deep well injection.
Atmospheric Emissions		
Central Treating Plant	Gaseous emissions arise from storage and separation tanks, the steam generators and flaring points.	Application of standard air pollution control technologies.
Casing Vent Gas	Produced steam which comes out of the wellhead contains small amounts of hydrocarbons, carbon dioxide, carbon monoxide, hydrogen sulphide, etc.	Aerial coolers for condensing steam, compressing and recycling of the vent gas to central recovery plant.
Ground Water Contamination	Ground water contamination can occur as a result of drilling wells, operation of injection production wells, waste water injection and leakage from surface ponds.	Casting of injection / production wells, lining of pits and ponds.
Land Use	Potential land use conflicts: trapping, timber harvest, recreation, agricultural operations.	Use of directional drilling from centralized well pads, use of consolidated common corridors for pipelines, powerlines and roads.

construction and operation of transportation pipelines from areas such as the Beaufort Sea will have to satisfy rigorous environmental restrictions.

2.3. Political Constraints

The general comments made in Section 1.3 about the effects of past regulatory activities and fiscal systems on the gas industry, also apply to the oil industry.

Government energy pricing policies and export controls during the 1970's had a significant effect on Canada's oil industry in the conventional oil areas. Conversely though, government policies during the same time-frame directed at oil self-sufficiency encouraged exploration in the frontier regions. However, crude oil supply has increased every year since 1982 and this trend continued in 1986 and 1987 notwithstanding the major drop in world crude oil prices that occurred in 1986. This can be attributed to a change in the operating climate resulting from reduced regulation of production and exports, the introduction of drilling, exploration and development incentives in 1986 and cost cutting measures implemented by industry which lowered operating costs in most areas (NEB, 1988).

In the area of oil sands and offshore development, government is seen as the promoter of mega-projects. Indeed, a lack of government involvement could be a potential constraint on the development of these resources. Most private companies are not prepared to bear the substantial risks involved in the current market environment. Governments can provide the flexible fiscal mechanisms that may be necessary to allow projects to proceed during periods of widely fluctuating market prices. As an example of the effect of government fiscal policy on the development of reserves, the recent demise of the "Petroleum Incentives Program" has resulted in a significant decrease in frontier drilling activity.

The petroleum incentive grants (PIP grants) were introduced as part of the National Energy Program of 1980 and were designed to promote regional and Canadian objectives. In essence, preferred write-offs were given to Canadian-owned firms doing exploration in frontier areas . The PIP grants were terminated on March 21, 1986. Table 7 shows the increase and then subsequent decline in activity during this time-frame.

2.4. Social/Economic Constraints

Social constraints with respect to the development and exploration of oil reserves in frontier areas are the same as for gas reserves.

Security of oil supplies can be viewed from either a Canadian perspective or from a North American perspective. Canada has estimated reserves that are one-fifth of those in the U.S. Since oil prices in both countries are now set by world oil prices, the most efficient use of resources may well mean acceptance of

Table 7. FRONTIER LANDS STATISTICAL SUMMARY

ACTIVITY STATUS ON FRONTIER LANDS	1983	1984	1985	1986	1987
Exploration Licenses/ Agreements Concluded	73	47	5	23	42
Wells Spudded	95	120	99	60	48
Metres Drilled	187,969	241,298	207,896	150,404	67,234
Wells Terminated	90	123	103	70	50
Significant Discoveries	5	11	15	14	1
Rig-Months	195	236	199	133	41
Geophysical Programs Run	84	65	55	15	7
km Shot	106,749	63,817	57,091	11,001	2,756

Source: The Canadian Oil and Gas Land Administration Annual Reports, 1983-1987 increased dependence on less expensive offshore imports for both countries and a decreasing concern about Canada's exposure to short term interruptions of oil imports. Movement in this direction is already apparent as over 60 percent of the increased demand for crude oil between 1985 and 1987 has been met by crude oil imports (CPA, 1988). As such, low market prices and an acceptance of greater reliance on offshore oil supplies may present serious constraints to the development of Canada's frontier and non-conventional oil reserves.

3.0. COAL

Canada has significant reserves of both thermal and metallurgical coals (Table 1). The importance of coal as an energy source for Canada and for export markets received much greater attention after the rapid escalation of oil prices in the 1970's. However, with the subsequent precipitous decline in world oil prices in the 1980's, interest in the use of coal as a substitute for oil has declined.

3.1. Technological Constraints

Transportation costs are the most significant constraints on western Canadian coals. As an example, transportation costs are equal to or exceed production costs for western Canadian bituminous coal delivered to Ontario ($78/t F.O.B. Ontario includes $36/t mining cost plus $42/t transportation cost) (Lobbe, 1988). Advances in shipping methods for western coals, i.e., larger unit trains, pipelining of coal or upgrading of the coal prior to shipment into a higher energy content form, all represent technological constraints to the increased utilization of these reserves. Mining costs and sulphur content are the most significant constraints on eastern Canadian coals (NEB, 1986).

Significant efforts have been made during the last 15 years towards developing new technologies for coal gasification, coal liquefaction, coal-oil co-processing, etc. However, the current status of these technologies is such that massive amounts of capital are required for economies of scale and current world oil prices do not allow enough margin to cover the operating costs. Technological breakthroughs will be required to permit smaller scale installations and more efficient operating plants before Canada's coal reserves can be developed for processing into alternate forms of energy (other than the generation of electricity).

3.2. Environmental Constraints

Environmental safeguard procedures with respect to the exploitation of Canada's coal reserves are well established, and any environmental constraints on the mining of reserves can be met by current technology.

3.3. Political/Economic/Social Constraints

None have been identified for the mining of Canada's coal reserves for use in Canada.

The single major economic constraint on the continued exploitation of western Canadian coal for export is the price of coal in the international market (Table 8). Canadian coal has to compete with lower priced Australian, South African, U.S. and Columbian coals. Stiff international competition represents a

Table 8. WORLD COAL IMPORT MARKETS IN 1985

PRODUCER	IMPORTER, mmt/y		PRICE $lt[1]	
	ASIA	EEC	ASIA	EEC
CANADA				
Metallurgical	25	1	62	56
Thermal	3	2	39	43
U.S.A.				
Metallurgical	18	29	63	57
Thermal	5	18	52	53
AUSTRALIA				
Metallurgical	44	12	50	53
Thermal	28	12	40	47
POLAND				
Metallurgical	-	6	-	55
Thermal	-	15	-	40
SOUTH AFRICA				
Metallurgical	6	-	43	39
Thermal	11	31	42	38

[1] delivered

SOURCE: Improving International Competitiveness Of U.S. Coal, U.S. National Coal Council, June 1987 significant constraint not only for potential new mining operations, but also for current production for the export market.

4.0. ELECTRICITY

Construction of new electrical generating plants requires long-range planning. Unfortunately, it is not always possible to predict future economic cycles which influence energy requirements. Consistent economic growth during the 1970's created expectations for significant additional generating capacity requirements (Table 3). However, reduced demands for electricity resulting from high energy prices and a recession left most utilities across Canada with significant excess capacity (about 53 percent) in the early 1980's (CPA, 1988).

Electricity is a very flexible energy form which has a high degree of market interchangeability with oil and gas. Electricity, decoupled from its method of generation, is a preferred source of energy for environmental reasons. As an export "product", most Canadian provinces have significant inter-ties with U.S. markets (in 1985, 10.7 percent of Canada's electrical production was exported to the U.S.) (CPA, 1988).

The demand for electricity is increasing and it will likely grow faster than the demand for oil or gas.

4.1. Technological Constraints

Increased utilization of Canada's potential and current hydro-electric generating sites will in part depend on technological innovations with high voltage direct current (HVDC) transmission, and superconductivity transmission.

Increased generation of electric power from lower quality coals will depend on new environmental control technologies such as smaller-sized fluidized bed combustion boilers, integrated coal gasification combined cycle plants, and more economical scrubbers or alternative control technologies for sulphur oxide and nitrogen oxide control. Increased generation from nuclear fuels will require solutions to the general negative public perception of nuclear power generating technology and the development of new techniques for the disposal of nuclear wastes. New technologies such as fusion could result in much cheaper electricity and hence, an economy based much more on electrical energy. Tidal power generation is another technology that has some potential although it requires a breakthrough. The latter technologies will not be viable until much into the future.

In general, Canada possesses significant untapped hydro-generating capacity as well as the resources to produce significant amounts of electricity from coal or uranium. The only serious current technological constraint to the effective utilization of Canada's conventional generating capacity on a national level is the lack of ties between the various provincial utilities. In addition, several provinces have significant undeveloped hydro sites which are currently constrained by the economic and technical difficulties of long distance transmission.

4.2. Environmental Constraints

Coal-fired generating facilities have well established environmental constraints such as sulphur dioxide and nitrous oxide emissions, fly ash and bottom ash disposal problems and water contamination problems. The plant emissions are governed by provincial environmental protection acts with the national objectives being set by federal government guidelines. In addition, substantial emissions of carbon dioxide from coal-fired plants, in the face of growing concern over the "greenhouse" effect, makes coal-fired electrical generation even more unattractive from an environmental perspective.

Nuclear generation has the problem of the safe disposal of nuclear wastes.

Hydro-electrical generation may have a secondary environmental constraint as a result of the "greenhouse" effect. If rainfall is reduced in the hydro-electric generating areas of the country, significant reductions in generating capacity could result. A summary of various utility environmental concerns is shown in Figure 2.

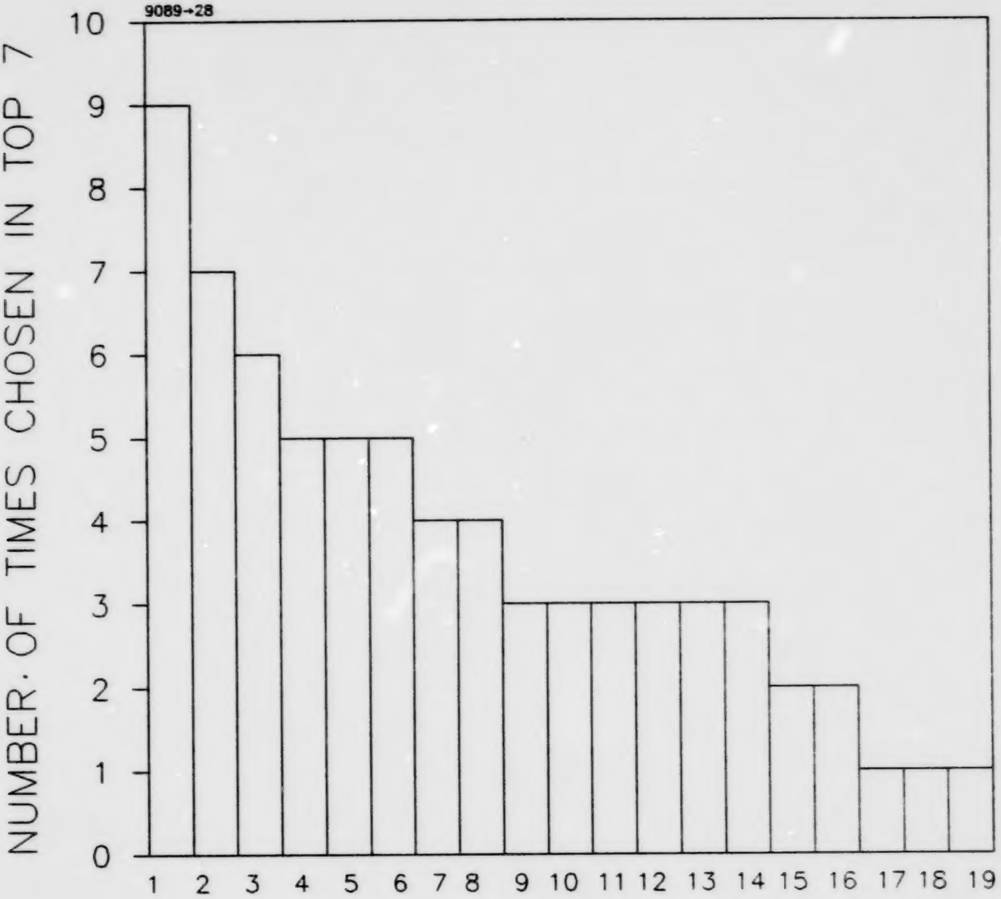

Figure 2. FREQUENCY OF OCCURANCE OF ENVIRONMENTAL ISSUES AS HIGH LEVEL CONCERNS

1. PCB's
2. Reg. App.
3. Haz. Waste
4. Tran. Line
5. Acid Rain
6. Herbicides
7. Land Use
8. Gen. Air Qual.
9. Social Costs
10. Particulates
11. Dams & W.O.
12. Fish Pass-Dams
13. Aesthetics
14. River Erosion
15. Dioxins
16. Hv Lines-Bio Eff.
17. Ash Disposal
18. Decomm'g
19. Spent N-Fuel

Source: Effer, et al. (1985)

4.3. Political Constraints

A major political constraint is the fear of some U.S. regulatory agencies that an excessive reliance on Canadian electrical imports will affect national security.

In Canada, the NEB has relaxed the regulatory process with respect to electrical exports for the U.S. However, domestic electrical production is regulated by provincial agencies. The provincial regulatory bodies in general are not concerned with the most efficient utilization of the Canadian electrical generating and transmission capabilities on a national level. This could be perceived as a constraint on the extent to which electrical generating reserves can be developed for domestic use.

4.4. Social/Economic Constraints

There is a growing concern that prices for electrical energy in Canada do not represent the full cost of the energy commodity including environmental and social costs for production and transportation. With the substantial increase of electricity exports to the U.S. and growing market competition between electricity, oil and natural gas, this could become a significant constraint.

For example, provincial hydro utilities have often been used as tools of economic development. Provincial debt guarantees, exemptions from corporate income taxes, low target rates of return, low water rental rates etc., arguably contribute to under-pricing of the final commodity. Construction of generating capacity to serve export markets could therefore be inconsistent with the mandate of some of the public utilities. Further, it could be argued that subsidized electrical energy sends the wrong pricing signals to consumers and is therefore competing unfairly with other energy commodities in a deregulated market place.

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MAJOR CONSTRAINTS ASSOCIATED WITH MARKETS

1.0. CANADIAN ENERGY CONSUMPTION

1.1. Demand Patterns

During the period 1965-1985, Canadian energy consumption increased from 4369 petajoules to 7762 petajoules (CPA, 1987).* At the same time, Canadian Gross Domestic Product (GDP) increased from 175.3 billion dollars to 393.8 billion dollars (at 1981 prices) (Figure 1) (Stats Canada).

The growth of Canadian energy consumption exhibited two marked dislocations following the 1974-75 and 1980-81 recessions. Interestingly enough, it seems that the 1973 and 1978 oil price shocks affected the overall Canadian energy demand much less than it affected demand in other western countries. This may have occurred because of government regulation of crude oil and natural gas prices over that period, and because of a relative abundance of alternative energy sources in Canada (coal, natural gas, hydroelectricity, etc.).

The pattern of energy demand vs GDP shows that with the exception of the two dislocations, energy consumption parallels the change in GDP (Figures 2 and 3); however, the ratio of growth of energy

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* Note: There is a significant variation in reported Canadian energy consumption depending on the source of the data, e.g. for 1985, Stats Canada Reports 6571 PJ, CGA 7643 PJ, NEB 6938 PJ.

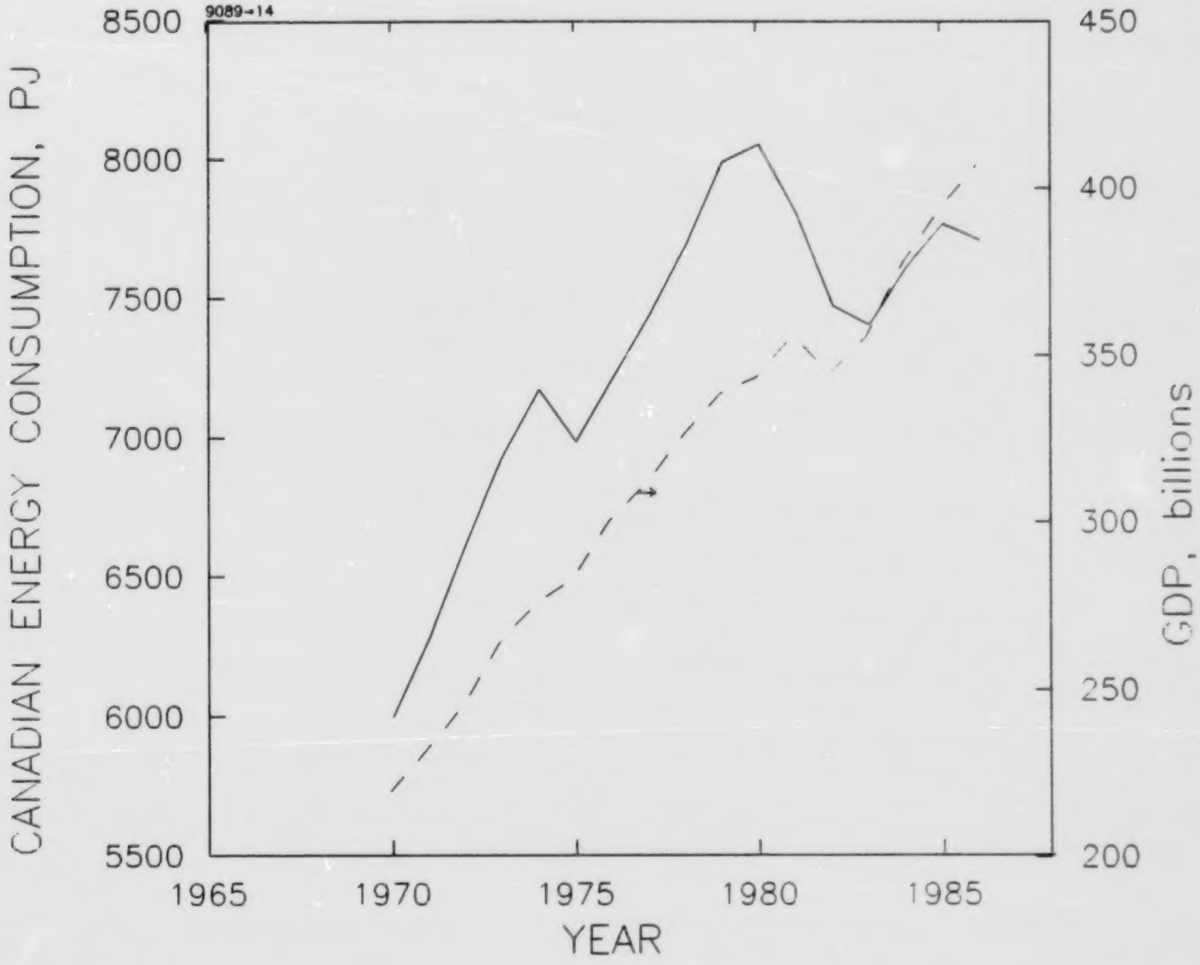

Figure 1. CANADIAN ENERGY CONSUMPTION AND GROSS DOMESTIC PRODUCT (1965-85).

Source: CPA (1987), Stats Canada (1988)

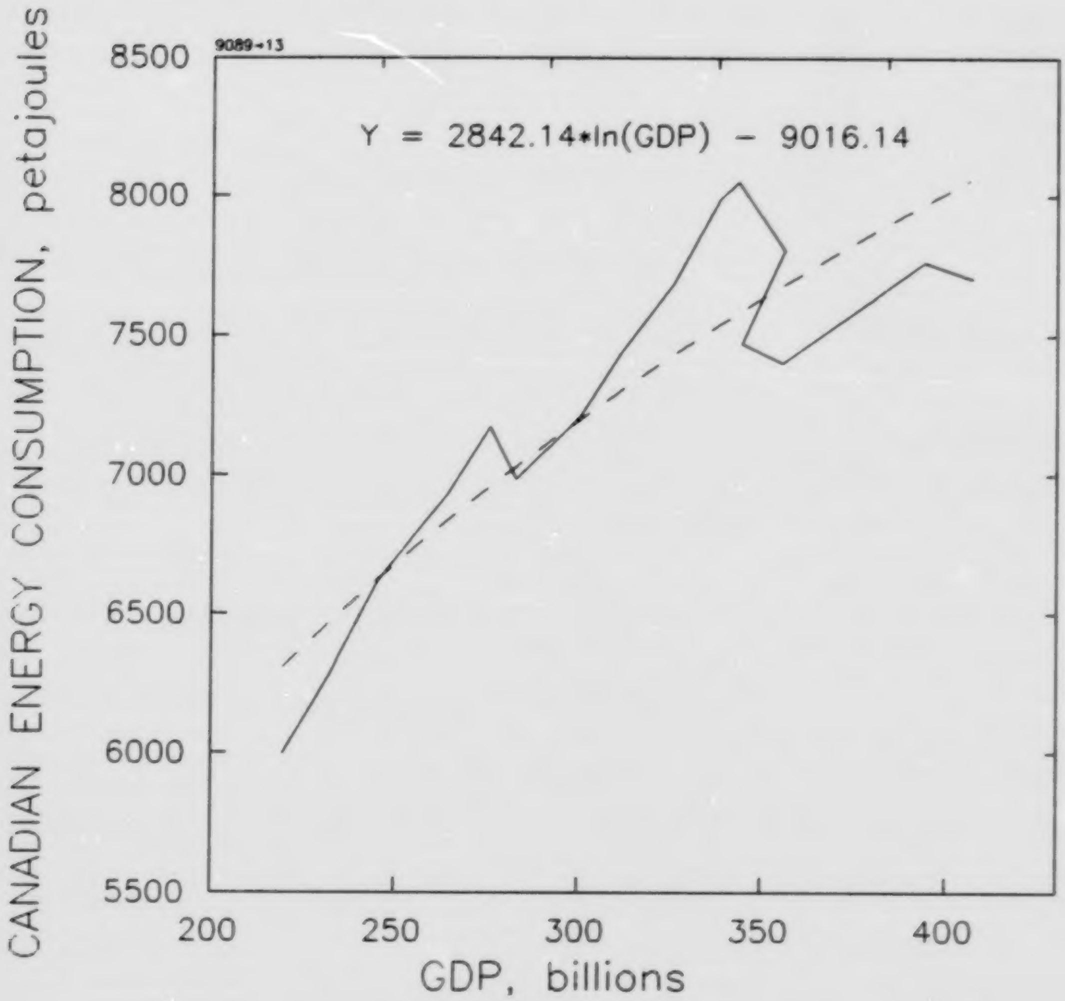

Figure 2. **CANADIAN ENERGY CONSUMPTION VS GROSS DOMESTIC PRODUCT.**

Source: CPA (1987), Stats Canada (1988)

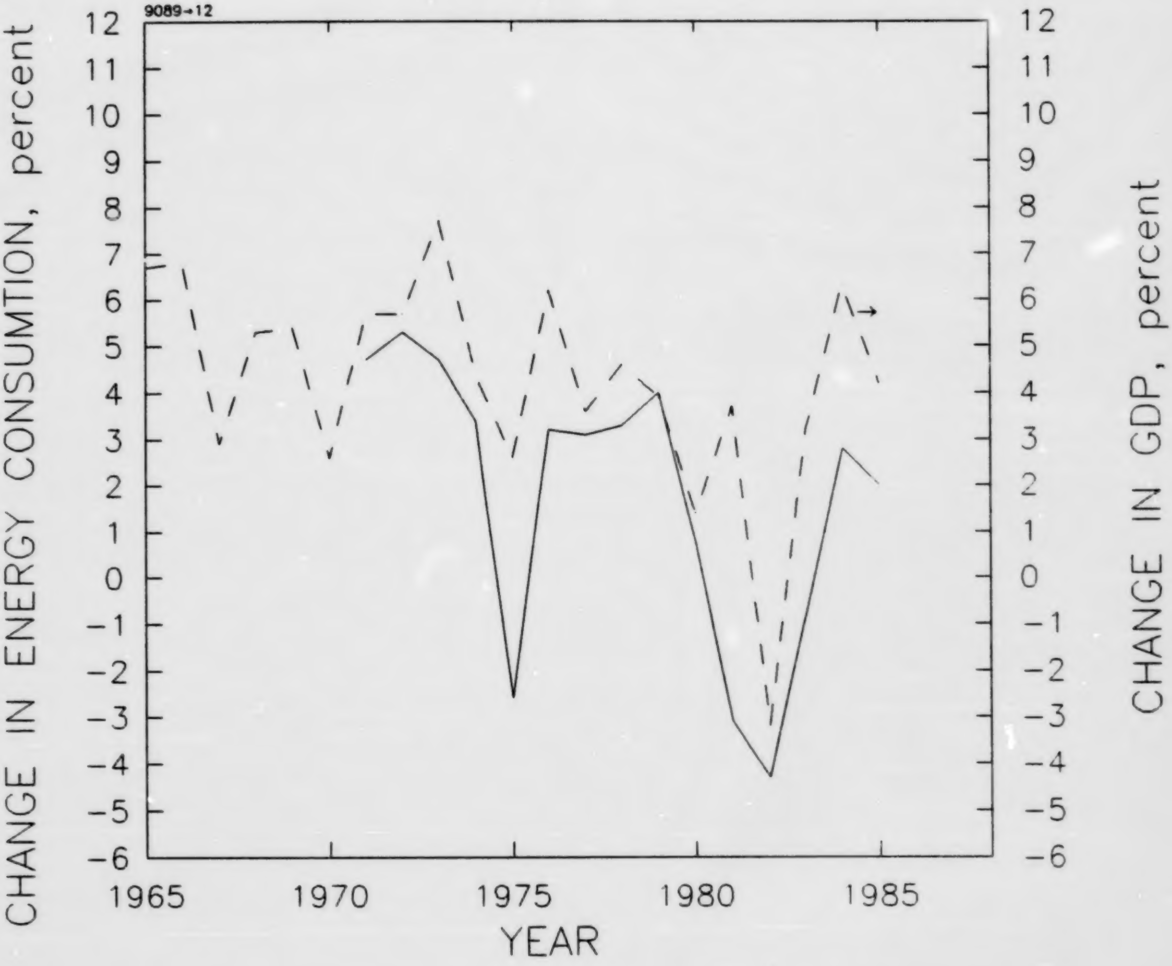

Figure 3. **CHANGE IN ENERGY CONSUMPTION VS CHANGE IN GDP (1965-85).**

Source: CPA (1987), Stats Canada (1988)

consumption to GDP, has decreased since 1970, reflecting structural changes in the energy use pattern and in the economy, i.e., a larger portion of the Canadian economy is now generated by service and high-tech industries, which are less energy intensive than traditional smoke-stack industries.

1.2. Market Constraints

The major constraint on Canadian energy consumption is the growth of gross domestic product. The other constraints include the availability and prices for alternative energy sources.

For example, the effect of GDP on Canadian energy consumption has been compounded by the change in crude oil prices. In the period 1973-83, a sharp increase in crude oil prices and a decrease in GDP have resulted in a reduction of energy consumption from a high of 8050 petajoules in 1980 to 7402 petajoules in 1983 (Figure 4). Following the GDP rebound in 1985 and a sharp decrease in crude oil prices, energy consumption increased to 7762 petajoules in 1985. During the 1970-85 period, Canadian energy consumers gradually shifted from petroleum products to natural gas, coal and electricity use (Figure 5). The 10 percent reduction in the petroleum market was gained by coal, electricity and natural gas, with the latter gaining a slightly larger share of the market.

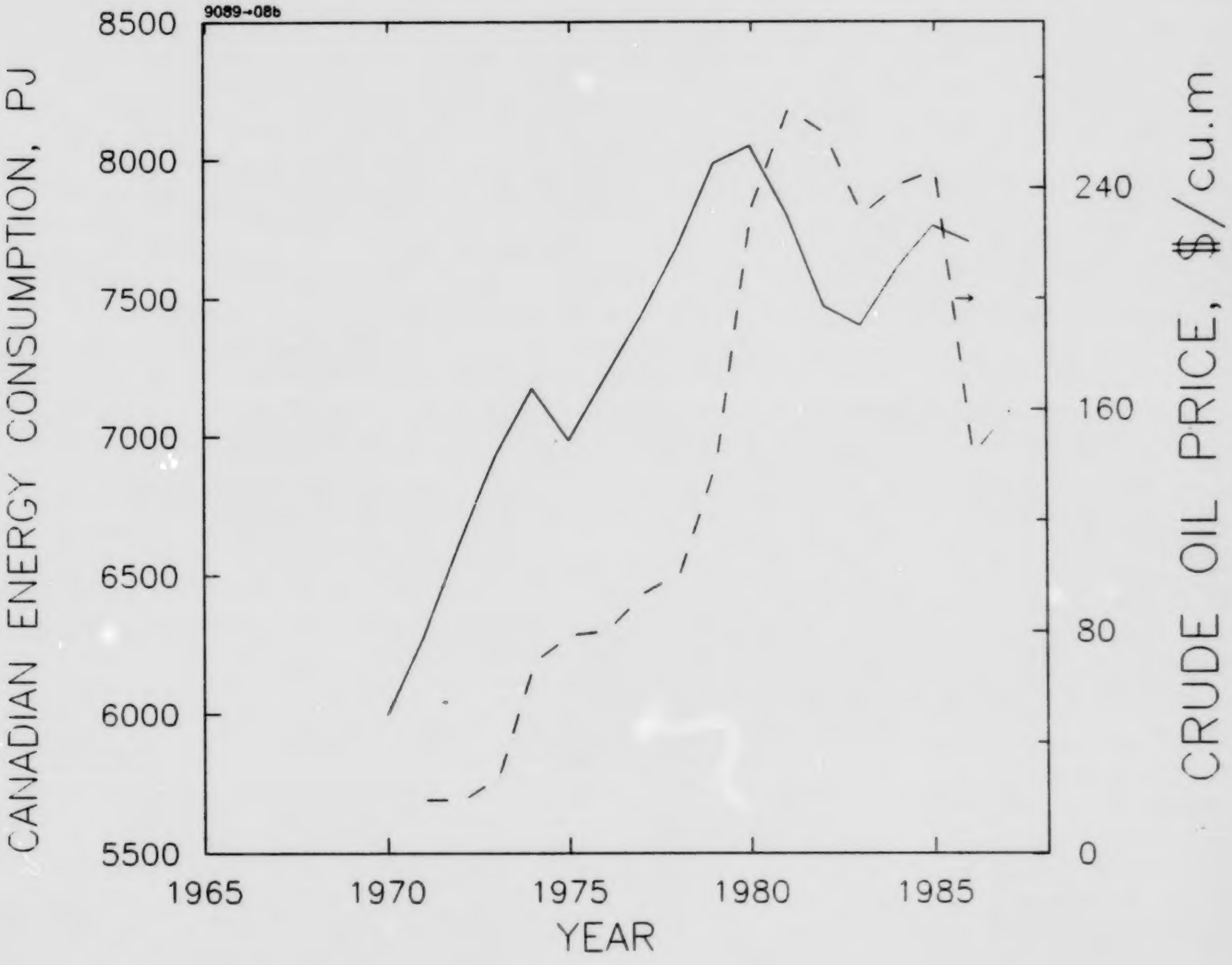

Figure 4. **CANADIAN ENERGY CONSUMPTION AND WORLD CRUDE OIL PRICES.**

Source: **CPA (1987)**

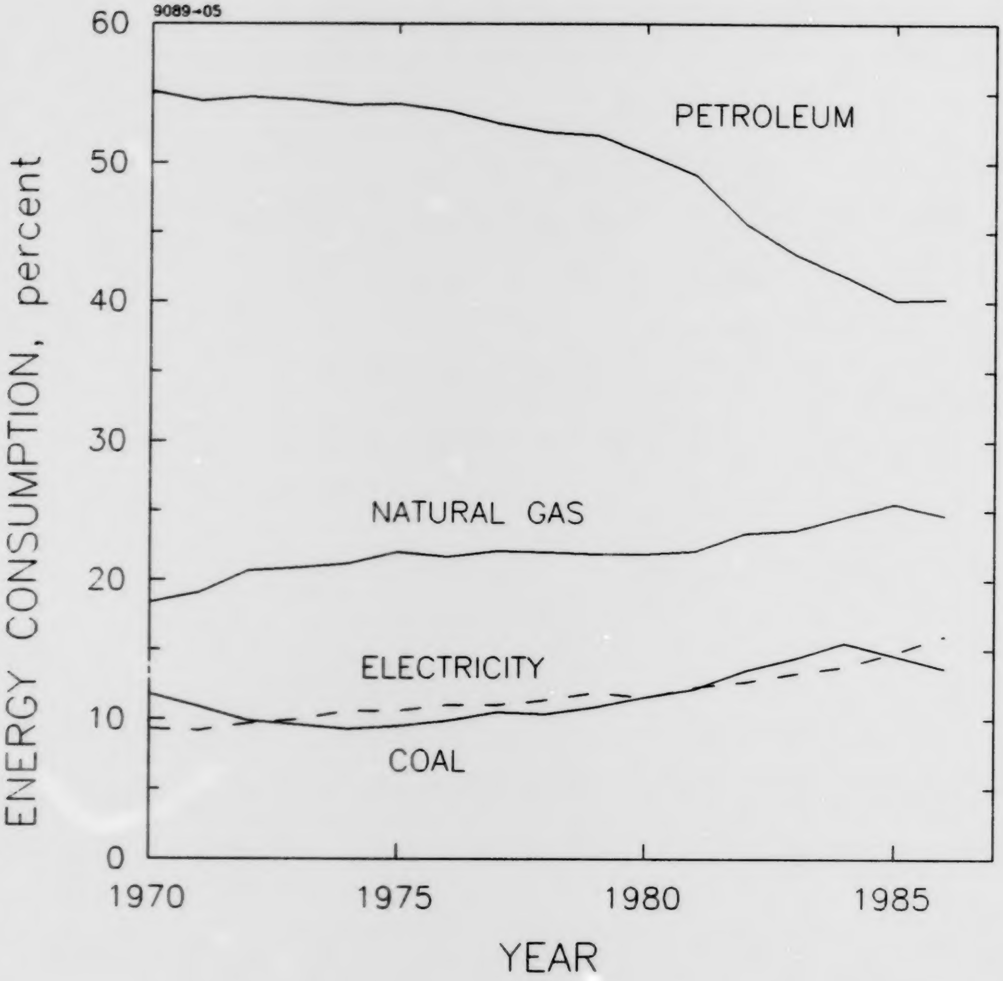

Figure 5. SOURCES OF ENERGY CONSUMPTION IN CANADA (1965-85).

Source: CPA (1987)

2.0. TRANSPORTATION FUELS

2.1. Demand Patterns

The demand pattern for crude oil in Canada in the last 20 years can be described as moving through three developmental phases. In the period 1965 to 1973 (Phase I), the demand for crude oil increased as the oil prices were low enough to encourage increased consumption (Figure 6). During 1973 to 1980 (II), crude oil consumption increased at a much slower rate and the fluctuations in demand reflected the price increases, regulatory price controls and boom/bust economic cycles. In the late 1970's and early 1980's crude oil consumption began a steep decline in response to sharp crude oil price increases, conservation measures and the poor performance of the Canadian economy in 1981-83. With the decrease of crude oil prices in 1985, we entered Phase III of the demand cycle, in which crude oil consumption leveled out and later increased. It could be considered that in Phase III the crude oil demand pattern returned to demand/price fundamentals (higher price, lower demand and lower price, higher demand). It is not clear, however, whether the reduction in demand in the price increase period will be matched by a similar increase in demand price elasticity in the price decrease period. It is expected that downward and upward price elasticity may be different due to conservation and more efficient utilization of technology, the switch to alternative fuels and, perhaps, a permanent change in the nature of the demand/price relationship for crude oil in Canada.

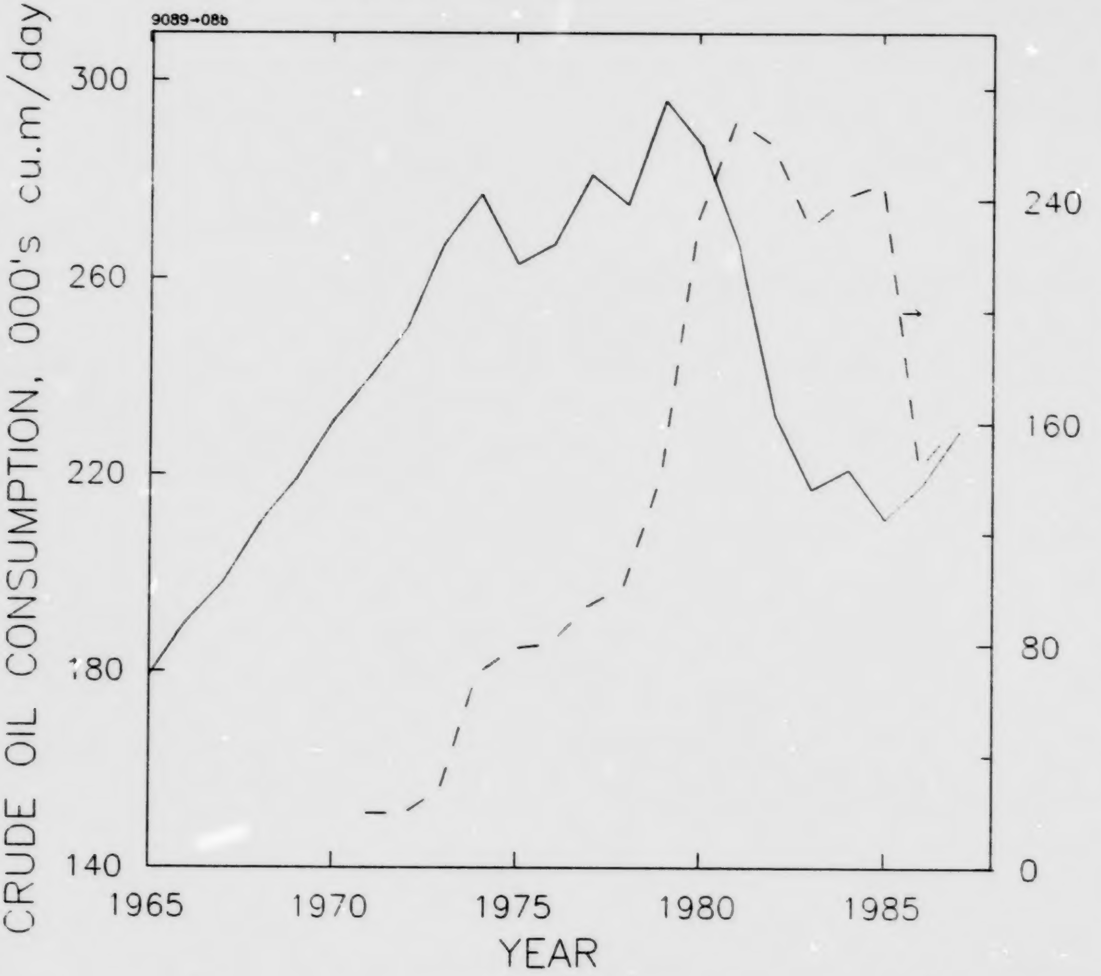

Figure 6. **CANADIAN CRUDE OIL AND EQUIVALENT CONSUMPTION AND WORLD OIL PRICES.**

Source: CPA (1987)

In Canada, oil is our most important energy source, accounting for about 40 percent of our total consumption in 1986, down from about 56 percent in 1973. It also represents Canada's major energy import (Stats Canada, 1965-1988).

In addition, over the last two decades oil use has been increasingly dedicated to transportation purposes because it is the major market area in which economic substitutes are not readily available.

During the period 1965-1985, consumption of transportation fuels increased from 1019 petajoules to 1610 petajoules (PJ). The consumption in eastern Canada increased from 352 PJ to 450 PJ, in Ontario from 333 PJ to 581 PJ and in western Canada from 334 PJ to 585 PJ (Stats Canada).

In the early 1960's, road transportation accounted for 75 percent of the transportation sector's end use oil demand and by 1985, it had risen to 81 percent (NEB, 1986). From 1973 to 1980, total transportation energy demand increased at an annual rate of 3.5 percent with the road transport increasing 4 percent annually. From 1980 to 1986, total demand for energy in the transportation sector decreased an average of 2.4 percent annually, with road transport decreasing by 2.5 percent annually. The decreases in transportation energy demand resulted from the world oil price "shocks" of 1973 and 1978-80, the increased vehicle efficiency in the post-1976 period and the general recession in the early 1980's (NEB, 1988).

When the 1973-74 and 1978-80 oil price shocks are compared, the 1973 shock had a much smaller effect on energy demand or demand for transportation fuels than the 1978 shock did. Two reasons are considered to account for this difference in reaction: 1) the 1978 oil price shock made oil somewhat less competitive, whereas the 1973 shock increased the price but oil still remained relatively competitive versus other fuels; 2) the 1978 shock triggered expectations of much higher oil prices in the future.

The use of fuel for transportation is very dependent on new car efficiencies, which have improved significantly over the last 15 years, the trend to smaller cars, the rate of automobile replacement and the distance driven. Fuel efficiencies for trucks have improved, but not as dramatically as for cars. The overall car stock fuel efficiency increased from about 16 miles per gallon in 1974 to 28 miles per gallon in 1986.

Airlines have improved load factors and switched to more efficient fleets because of high fuel costs and the 1981-82 recession. The effect of airline deregulation and the recent oil price decrease will likely be an increase in the demand for and use of aviation fuels.

Through the 1982-86 period, there was a sizable contraction in Canadian refinery capacity in response to the rapid decline in oil consumption (Figure 7). At the beginning of 1980, Canadian refinery capacity was over 360,000 m^3/day. By 1986, capacity dropped to less than 320,000 m^3/day, but the demand load was also reduced to 226,000 m^3/day (NEB, 1986). Between 1965 and 1986

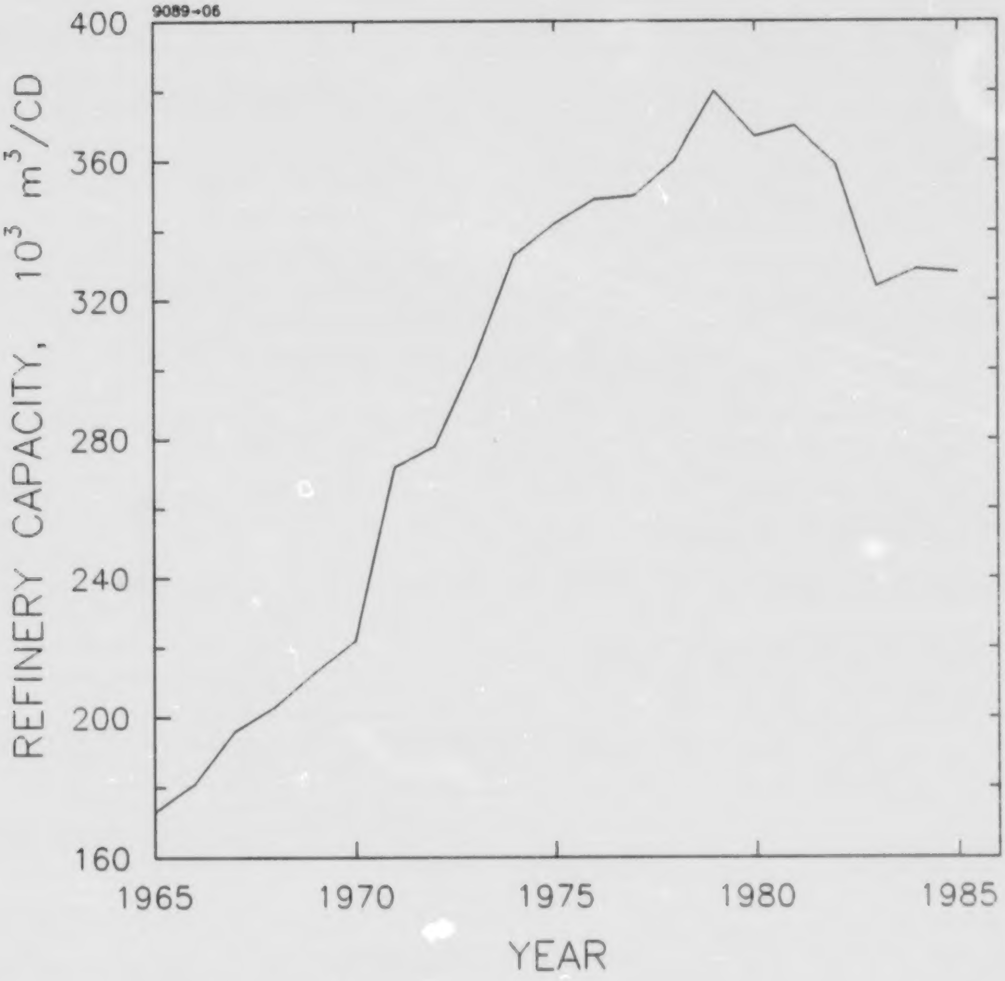

Figure 7. **REFINERY CRUDE OIL CAPACITY IN CANADA (1965-85).**

Source: CPA (1987)

there has also been a significant change in the refinery slate. In the 1960's and early 1970's, refinery production included about 35 percent gasoline, 16 percent light fuel oil, 22 percent heavy fuel oil and 11 percent diesel fuel, on average. In 1985 the refinery slate consisted of about 38 percent gasoline, 19 percent diesel and less than 10 percent light and heavy fuel oil. There has been significant growth in non-fuel refinery products such as petrochemicals and lubricants, and diesel fuel (Figure 8).

A pattern similar to that for crude oil was also exhibited by gasoline consumption between 1965 and 1985 (Figure 9). The gasoline consumption pattern can be divided into three phases reflecting crude oil pricing and the economic and regulatory environment over this time-frame: Phase I - 1965-73, Phase II - 1973-80 and Phase III - 1980 plus (Figure 9). It is interesting to note that despite strong regulatory policies governing the pricing and sale of gasoline, following the oil price shocks the demand for gasoline seems to have returned to market fundamentals.

Despite regulatory constraints implementing domestic ceiling prices on Canadian crude in the 1970's and early 1980's, Canadian gasoline prices seemed to follow the change in world oil prices (Figure 10). Canadian gasoline consumption has responded to the change in the growth of GDP in the 1970-1985 period. As in the late 1970's, when gasoline prices increased and the GDP slowed down, gasoline consumption decreased by over 6,000 m^3/day (about

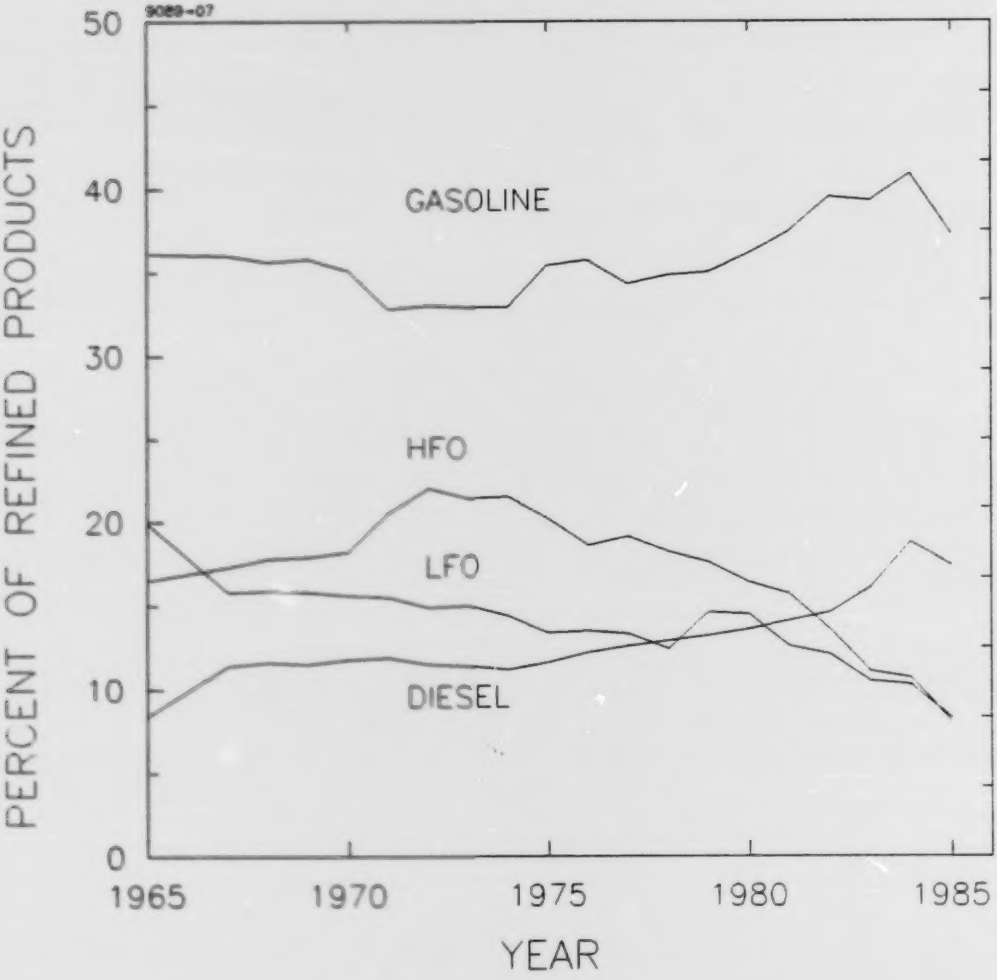

Figure 8. REFINERY PRODUCT SLATE IN CANADA (1965-85).

Source: CPA (1987)

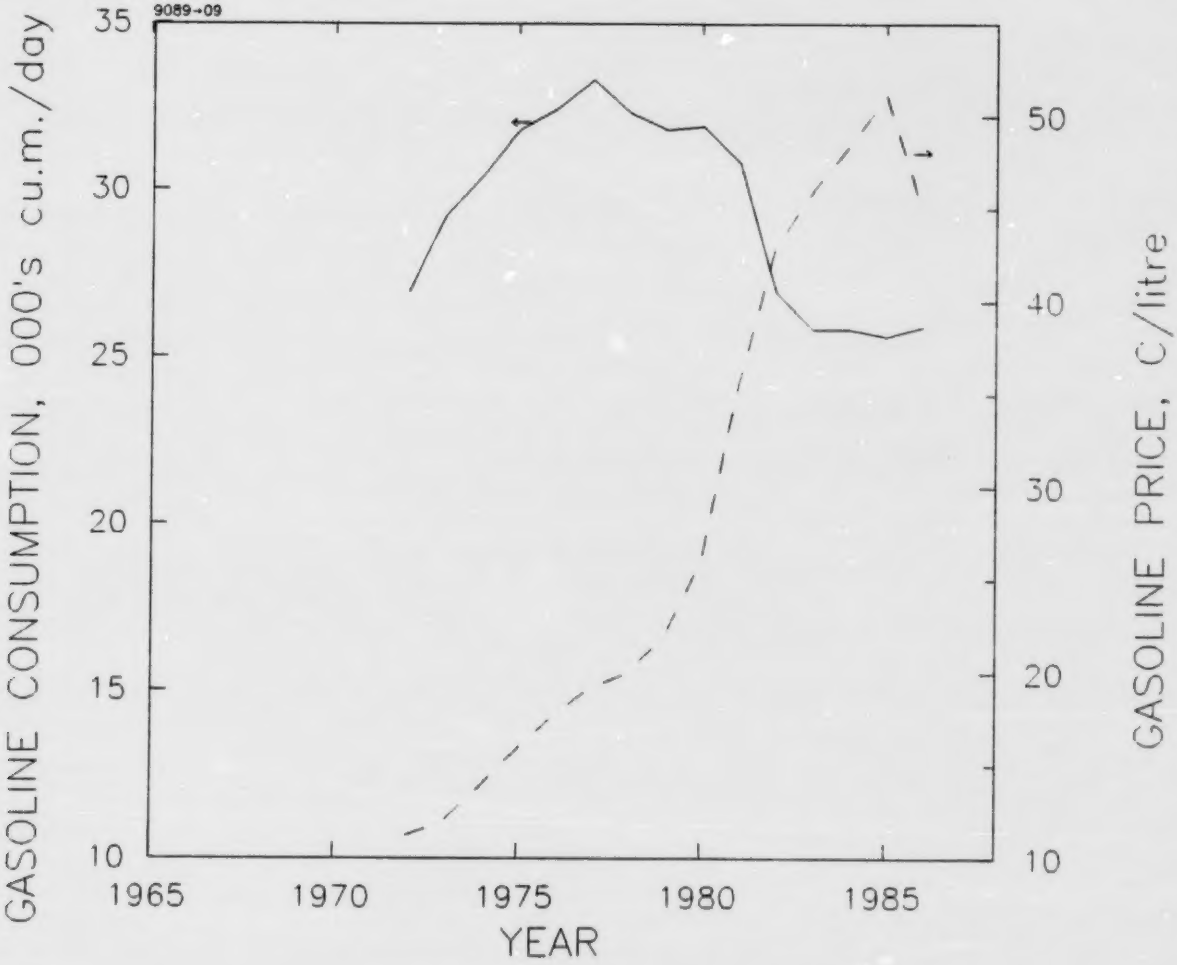

Figure 9. **CANADIAN GASOLINE CONSUMPTION AND REPRESENTATIVE RETAIL GASOLINE PRICES (1971-86).**

Source: CPA (1987), Stats Canada (1988)

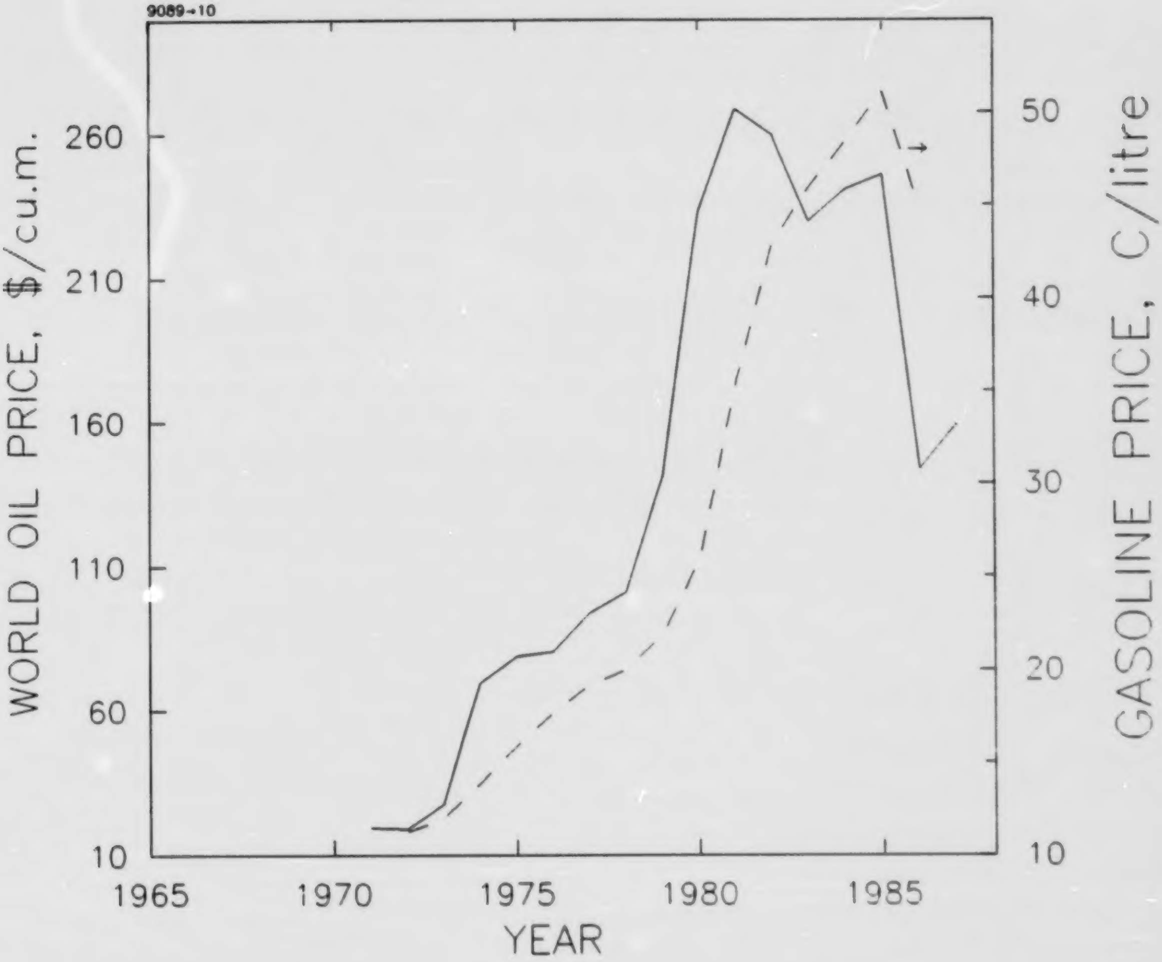

Figure 10. WORLD CRUDE OIL PRICES AND CANADIAN GASOLINE PRICES.

Source: CPA (1987)

25 percent) (Figure 11). When the GDP increased in 1983, the decline in gasoline consumption leveled off, and consumption has increased since 1985 indicating a return to market fundamentals.

2.2. Major Market Constraints

The combined effects of declining supplies of oil and increasing pollution from fossil fuel combustion will force changes in the fuels used for transportation. These changes are bound to be difficult because of the infrastructure in place to serve today's system.

Emissions from gasoline and diesel powered vehicles (CO_2, SO_2 and NO_2) cause acid rain and/or contribute to the "greenhouse effect". However, substitute fuels in most cases do not fare much better.

Lead emissions from gasoline driven vehicles have recently been a target for federal regulations that will see the removal of lead as an octane enhancer from gasoline in Canada by 1991. This octane enhancer must be replaced with other additives which may have their own environmental problems, or the fuel itself must be upgraded. Fuel upgrading has the effect of reducing gasoline yield because of increased severity of reforming. Either way the cost of producing gasoline is increased for the refiner.

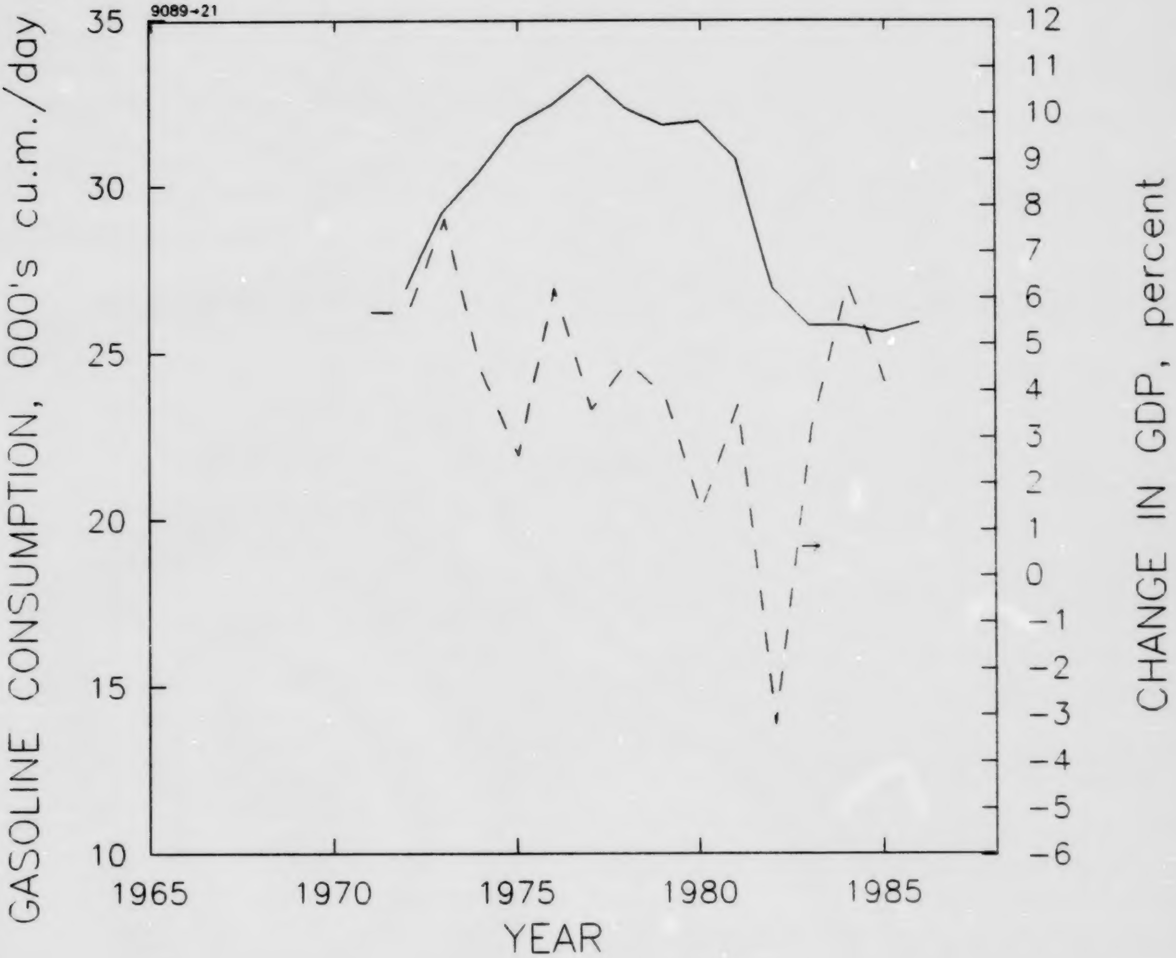

Figure 11. CANADIAN GASOLINE CONSUMPTION AND CHANGE IN GROSS DOMESTIC PRODUCT.

Source: Stats Canada (1988)

Stiffening waste disposal regulations will increase the cost of refining and storage of oil products and this will affect cost over time.

The transportation fuel market is the most vulnerable of all Canadian energy markets to the fluctuation in prices and demand/supply pattern of world oil. Canada has very abundant energy sources such as coal, natural gas and hydroelectric power. The reserves and production capacity of these resources are more than adequate for Canadian consumption; however, the Canadian conventional oil supply is estimated as sufficient for just over 10 years at the current rate of production of about 200,000 cubic metres per day (740×10^6 m^3 reserves/200,000/365). The Canadian reserve capacity has declined from 30 years in the 1960's, to about 13 in 1987, pointing to the failure of attempts to increase conventional resources and to the importance of heavy oil, bitumen and offshore resources in meeting future Canadian crude oil demand.

Although Canadian production of synthetic crude has gradually increased from 5,000 cubic metres in 1970 to over 47,000 cubic metres in 1987 (Figure 12), this production has not been sufficient to offset the decrease of 100,000 cubic metres for conventional oil production between 1970 and 1987 (Figure 12). It does meet, however, current Canadian needs for crude oil, with consumption of 224,000 cubic metres per day in 1986 versus total production of 232,000 cubic metres per day including synthetic crude and bitumen.

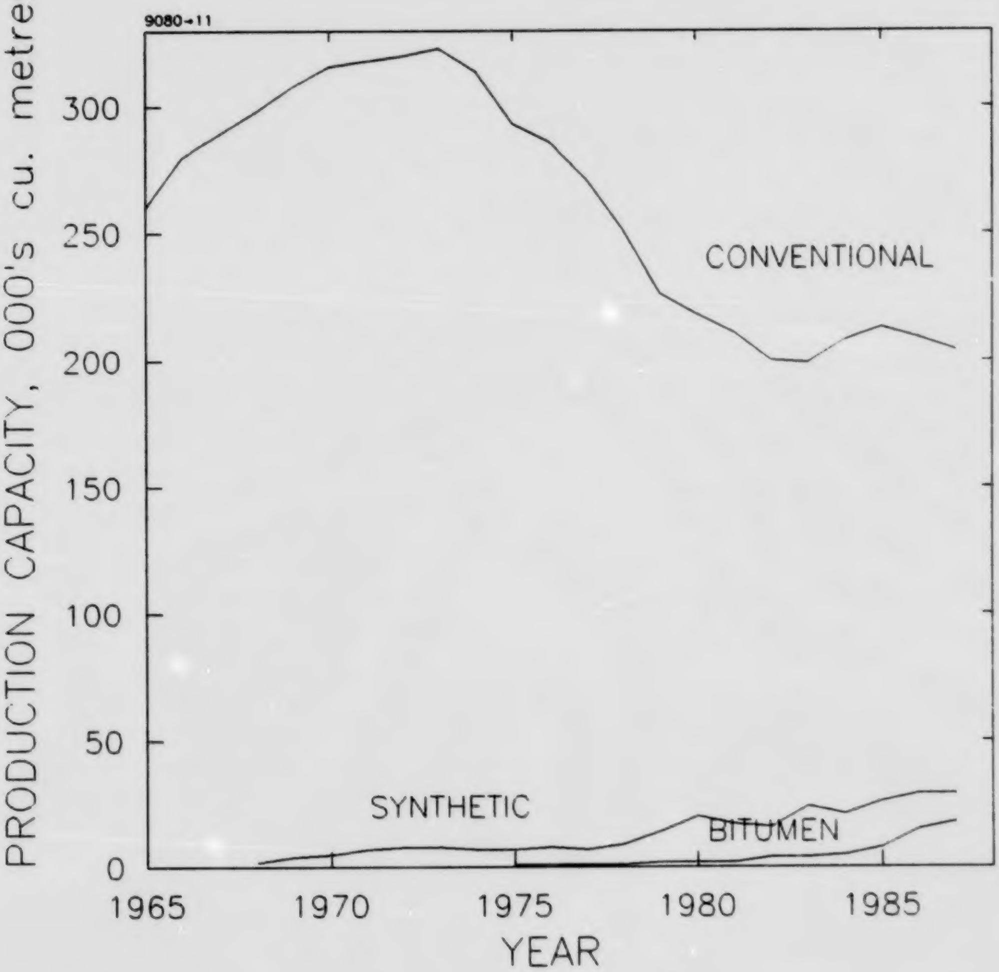

Figure 12. CANADIAN CRUDE OIL AND EQUIVALENT PRODUCTION CAPACITY (1965-85).

Source: CPA (1987)

Canada's refineries must be retrofitted to process heavy crude oils. Federal and provincial participation was necessary to construct the only heavy oil upgrader in Canada, The Co-Op Upgrader in Regina. Without additional capacity to refine heavy oil into transportation fuel, Canada will have to depend on imports to meet its requirements as Canada's conventional oil supplies decline.

In the short term, propane, compressed natural gas (CNG) and methanol are the alternates to gasoline and diesel. The federal government has, until recently, made grants available for conversion to propane or CNG, and provincial governments have, in some cases, lowered taxes on blends of oxygenates and gasoline.

In the medium to longer term, batteries, electrolytic hydrogen and the conversion of natural gas to liquid fuels are likely to complement gasoline and diesel fuels from conventional, heavy and synthetic crude oils. However, considerable development work is still required on the production, storage and utilization of new fuels. Also, engines that can use the new liquid fuels may have to be developed.

3.0. HEATING OIL

3.1. Demand Patterns

As a percentage of final energy demand, oil's share has declined from 54 percent in 1975 to slightly less than 42 percent in 1985 (CPA, 1987).

As noted in the previous section, oil has increasingly been dedicated to transportation purposes. Use of heating oil, which includes heavy oil used in industrial boilers and fuel oil for residential and commercial furnaces has decreased from 1033 PJ to 503 PJ over the 1965 to 1985 period. As a percentage of total refinery products output, heavy and light fuel oil decreased from a combined 37 percent of refinery products output in 1965 to less than 18 percent in 1985 (CPA, 1987).

During the 1970's and early 1980's the government had programs to switch consumers from heating oil to alternate fuels, as well as programs to increase building insulation and to replace inefficient industrial equipment with efficient equipment. Paradoxically the federal government also set Canadian oil prices below world oil prices from 1973 to 1985 which, in general, distorted the prices for refined oil products such as heating oil.

In the residential sector, 85 percent of energy is used for space and water heating, of which 51 percent is supplied by natural gas and 7 percent by kerosene and light fuel oil (NEB, 1986). The rest is supplied by electricity. In the commercial sector, two-thirds of energy is used for heating and cooling buildings. In so far as fuel oil is used for residential and commercial space heating, the replacement of old furnaces with new equipment (new furnaces are approximately 10 percent to 40 percent more efficient than existing stock); the upgrading of insulation in old buildings; the addition of newer, more energy efficient houses and commercial buildings; the use of set-back thermostats and microprocessors to control a building's energy use, etc.; have all contributed to a decrease in demand. This trend will continue simply because it is not possible today to buy other than an energy efficient house or a fuel efficient commercial space heating furnace, no matter the fuel of choice.

3.2. Major Market Constraints

Over the longer term, a reduction will have to take place in Canada's reliance on oil as a source of energy for space heating and industrial application. This will occur not only because of the global warming and acid disposition associated with fossil fuels, but more particularly because the bottom of the oil barrel is in sight.

The U.S. Geological Survey estimated in 1985 that proven global reserves of crude oil represent about 36 years of present levels of world consumption. Yet undiscovered conventional crude represents about 26 years and it is by no means certain that these resources will be found. Therefore, assuming no major new discoveries or technological breakthroughs, oil will become much too scarce and much too expensive to use for space heating or for steam generation. Natural gas and electrical energy are readily available alternates to oil for space heating and industrial applications.

In Canada, natural gas is available for industrial and residential uses in all provinces except the Atlantic provinces. Natural gas should be available in the Atlantic provinces in the medium-term from the Grand Banks and the Scotia Shell. In Ontario and Quebec, there is significant competition between natural gas and fuel oil as an industrial fuel. Electricity competes with fuel oil for space heating in Ontario, Quebec and the Atlantic provinces. As well, electricity is used in the Eastern provinces for steam generation in industrial boilers.

Many new industrial boilers are dual-fired to burn either fuel oil or natural gas, and in some provinces residential furnaces are dual fuel. For example, by 1984, largely as a result of the federal government's Canadian Oil Substitution Program, five percent of Quebec's housing stock had dual heating capability with the capability of either burning heating oil or utilizing electricity (NEB, 1986).

4.0. ELECTRICITY

4.1. Demand Patterns

Consumption of electricity in Canada increased from 518 PJ to 1336 PJ between 1965 and 1985. Consumption in eastern Canada has more than doubled from 217 PJ to 569 PJ, in Ontario consumption has doubled from 177 PJ to 405 PJ and in western Canada it has tripled from 124 PJ in 1965 to 359 PJ in 1985.

The growth of electrical energy production resembles the Canadian energy consumption pattern. There has been a steady increase in electrical energy production with exceptions for the 1973-74 and 1978-81 periods when a decrease in GDP reduced the demand for electricity (Figure 13). The demand for electricity in the industrial sector also steadily increased during the 1965-85 period, with some reduction in the demand during the recession periods. It is interesting, however, that in contrast to Canadian energy consumption which remained below the level of 1980, production of electricity and industrial consumption have increased substantially since 1980, underscoring the relationship between GDP and electricity demand.

The pattern for electricity export is somewhat different from the production/consumption pattern. In the periods 1973-75 and 1978-80, there was an actual increase in export demand, most likely due to the replacement of petroleum based generation in the U.S. with Canadian exports.

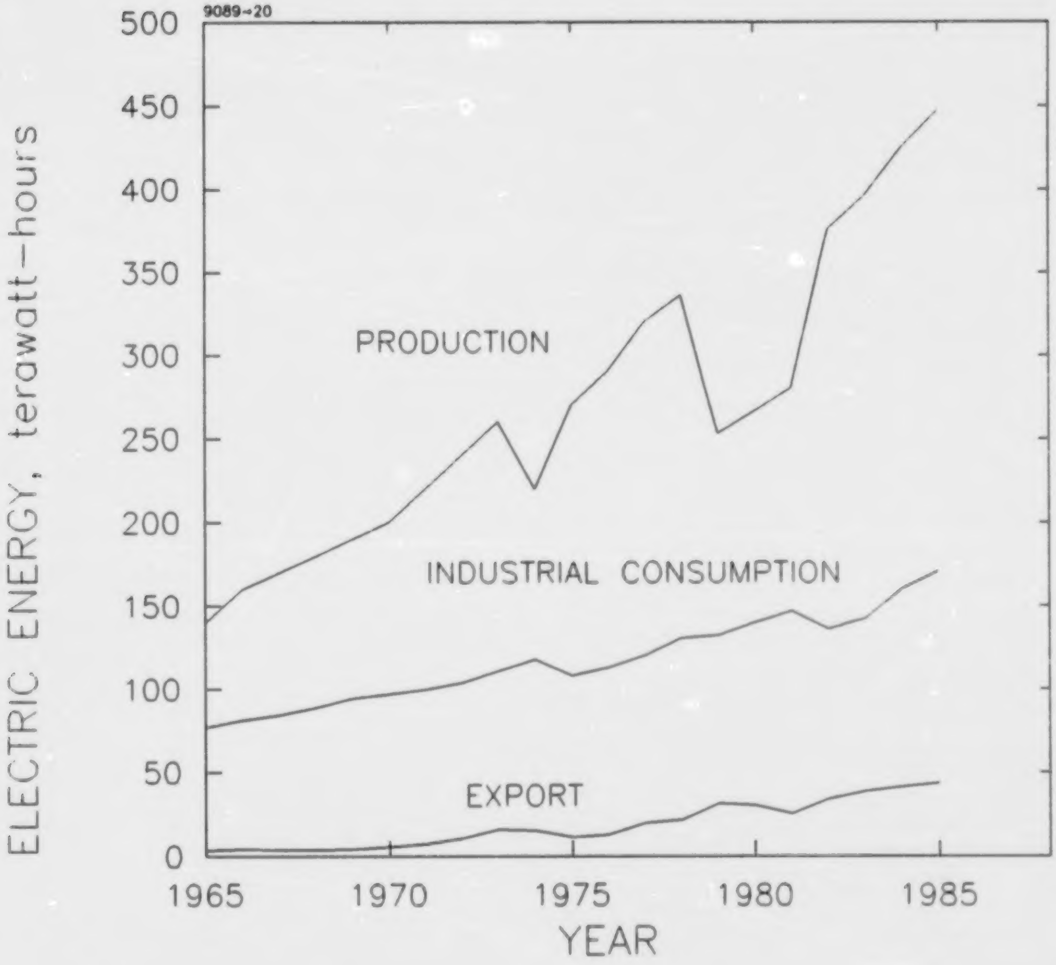

Figure 13. CANADIAN ELECTRIC GENERATION, EXPORT AND INDUSTRIAL CONSUMPTION.

Source: Stats Canada (1988)

The pattern of use of fossil fuels for generation of electricity in Canada has significantly changed over the last 20 years. In 1965, the amount of electricity generated from natural gas was 4.7 Twhrs, from coal 15.7 Twhrs and from petroleum 2.6 Twhrs. In 1985, natural gas generators produced 1.5 Twhrs, coal produced 81 Twhrs and petroleum generators produced 4.7 Twhrs of electricity (CGA, 1986). Clearly, the only fossil fuel which was used in greater quantity for electricity production. Natural gas and petroleum maintained only a marginal position.

The pattern of electricity generation from natural gas and petroleum shows two different trends in the 1965-85 period. Up to 1975, as prices for natural gas and petroleum remained relatively low, the amount of both fuels used for generation of electricity increased (Figures 14 and 15). However, as the prices for natural gas and petroleum rapidly escalated in the second half of the 1970's, the use of both fuels for power production rapidly declined. In contrast, the use of coal for electricity generation experienced a steady growth throughout the 1965-85 period, with coal becoming the preferred utility fuel in the 1970's and 1980's (Figure 16).

4.2. Major Market Constraints

There do not appear to be any significant impediments to electricity increasing its percentage of final energy demand in

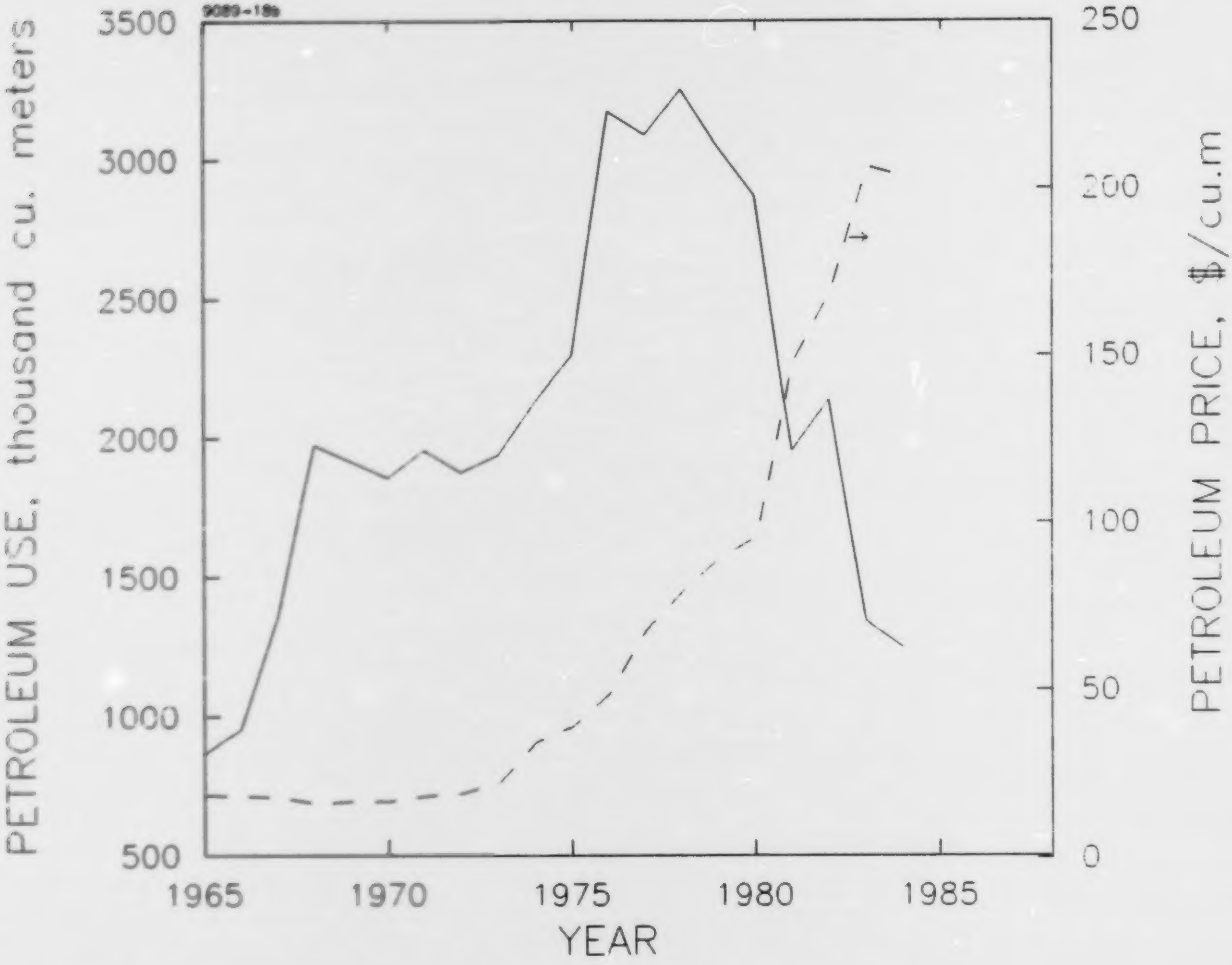

Figure 14. USE OF PETROLEUM FOR PRODUCTION OF ELECTRICITY.

Source: CGA (1986)

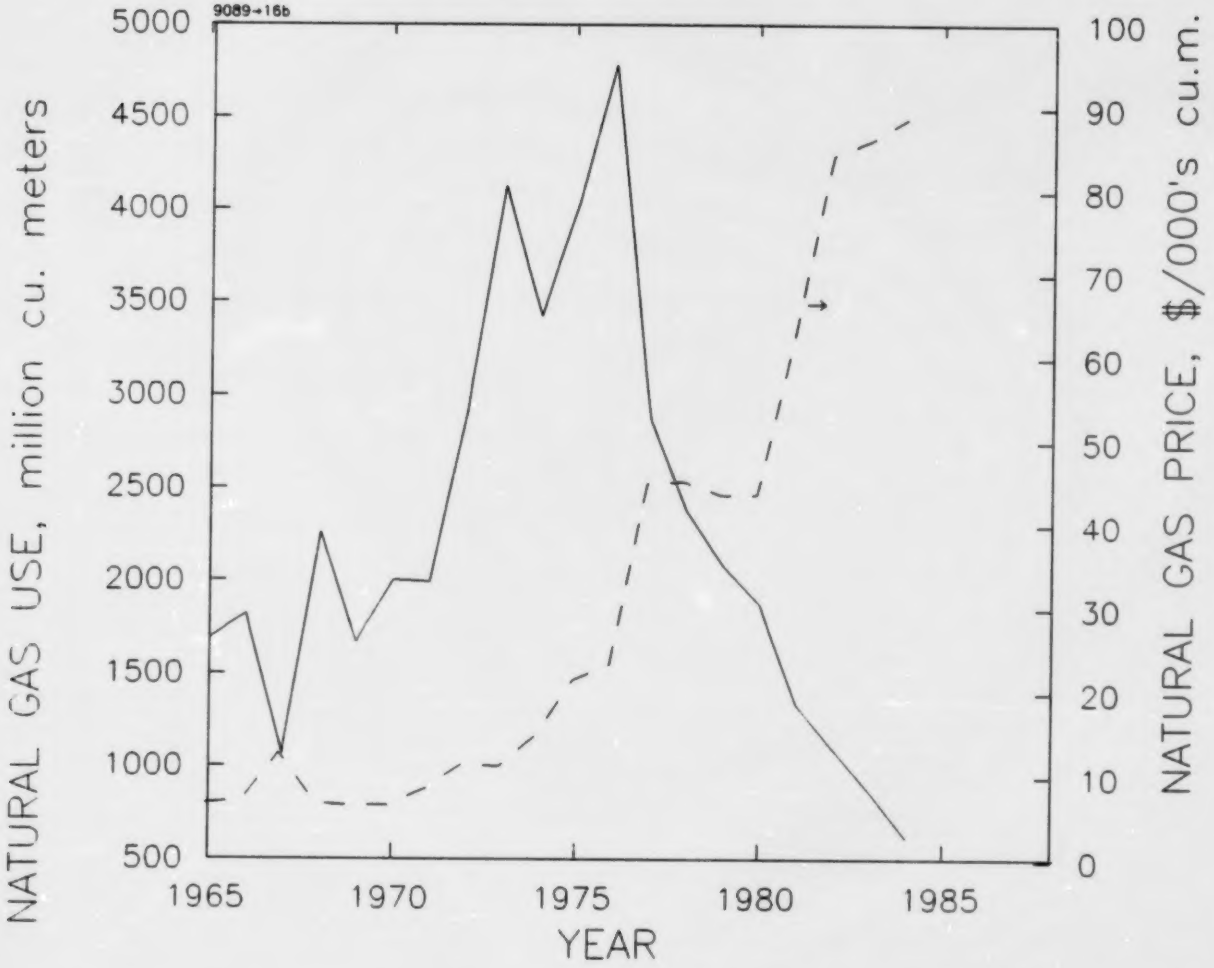

Figure 15. **USE OF NATURAL GAS FOR ELECTRICITY PRODUCTION (1965-85).**

Source: CGA (1986)

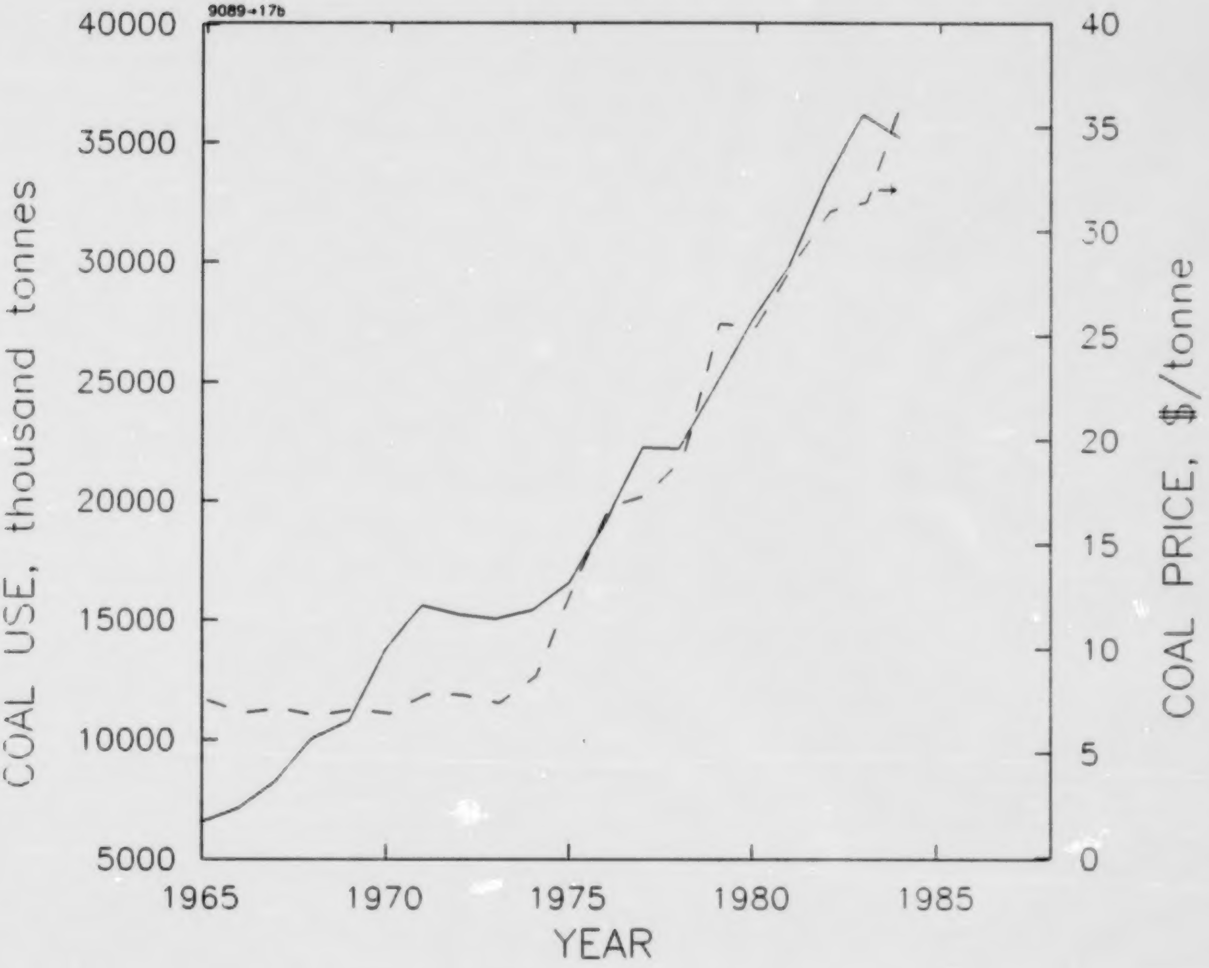

Figure 16. USE OF COAL FOR ELECTRICITY PRODUCTION (1965-85).

Source: CGA (1986)

Canada or to a continued growth in the amount of electricity exported to the U.S.

Over the short term, with depressed oil and gas prices, electrical demand will be down in the oil producing parts of the country and competition with natural gas and fuel oil will be fierce in the markets where head-on competition can take place. However, increased industrial and manufacturing activity fueled by cheap energy prices creates an increased electrical demand in Ontario and Quebec. Canada is also undergoing a shift out of primary industries into secondary service industries which are much more reliant on electricity per unit of GNP.

In the industrial sector, electricity offers a great deal of flexibility in terms of dual fired capabilities and the demand for electricity should grow faster than the demand for oil and gas. Increased consumption in the residential sector will result from a growing convenience oriented lifestyle and the use of electrical energy directly for space heating or through the use of heat pumps. However, the major constraint for growth in the use of electricity as a replacement fuel for either heating oil or natural gas is the relative price of electricity.

Transmission systems and inter-ties between provinces and the U.S. represents the only significant technological constraint to increased markets in Canada or the U.S. Lack of ties between some provinces does not allow the maximum benefits of shipping surplus generating capacity in Canada. Lack of these ties and restriction to some transmission systems in the U.S. (i.e., transmission lines belonging to the Bonneville Power Administration in the north western U.S.), affects utilities wanting to export surplus power.

Over the longer term, if there is a world-wide agreement on significant reductions in CO_2 emissions to the atmosphere, Canada would need to transform its energy system to one relying on nuclear energy (which has warts of its own), and to hydro electricity with significant downstream changes requiring implementation of electro-technologies.

5.0. COAL

5.1. Demand Patterns

The demand for coal in Canada has increased from 660 PJ in 1965 to 1133 PJ in 1985. This includes coal used for electricity generation as well as for industrial, domestic and farm uses. In the industrial sector, coal use decreased from 288 PJ in 1965 to 46 PJ in 1985. The percentage of coal in total Canadian energy use decreased again after 1985, with decreasing natural gas and crude oil prices (Figure 5).

The importance of coal as an energy source in industry diminished during the 1950's and 1960's due to the increasing use of lower priced and more convenient energy forms provided by oil and gas. However, interest in coal reversed after the rapid escalation in oil prices during the 1970's (Figure 7). Western coal began to be used in Ontario and exports of coal - primarily metallurgical coal - to Korea and Japan, increased significantly.

The production of coal has increased in Canada every year since 1969 so that by 1985 it accounted for 15 percent of Canada's primary energy production. In terms of coal for the export market, prior to 1970 very little coal was exported from Canada. In 1970 exports were only 4 megatonnes going to 27 megatonnes in 1985. Since 1985, coal exports have decreased due to decreased world wide-demand for metallurgical coals (NEB, 1986).

5.2. Major Market Constraints

In Canada, coal is used primarily for the generation of electricity. In-so-far as the effects of economic growth and various consumption affect the requirements for electricity, so will the amount of coal required for electrical generation be affected.

The most important current constraint with respect to the use of western Canadian coal in Canada is Ontario Hydro's decision concerning the use of coal for electrical generation in that province and the source of that coal. As a low sulfur fuel, Western Canadian coal offers environmental advantages. However, from a cost perspective it may well be economically more efficient for Ontario Hydro to burn higher sulfur content U.S. coals while at the same time installing sulfur scrubbing equipment in its generating plants.

Although limited by environmental considerations and market price constraints opposite natural gas and heavy fuel oil in most parts of the country, the use of coal as a cheap boiler fuel cannot be ignored. The proximity of massive U.S. coal reserves with falling unit costs of production could create a competitive fuel market situation, should world oil prices recover. However, increased U.S. coal imports would also present a significant constraint to the increased exploitation of western Canadian coals for the Ontario market. Transportation costs are a major constraint on the increased use of western Canadian coal in eastern Canada in this type of a world oil price scenario.

In addition to the market constraint of pricing opposite natural gas and fuel oil in Canada, coal is generally perceived to be a "dirty" fuel, which has significant material handling problems associated with its use. The emission problems from coal burning operations are several; CO_2, NO_x and SO_2 emissions, as well as the disposal of scrub slurries and dry ash byproducts from stack gas cleaning operations.

With respect to exports, Canadian thermal and metallurgical coal is subject to stiff offshore competition from Australian, South African and U.S. coal and more recently coal from China, Columbia and Venezuela. The drop in world oil prices has made thermal coal less attractive opposite fuel oil for steam generation. In addition, the increased use of plastics and ceramics in place of iron and steel has affected the growth rate in the demand for metallurgical coal.

During the late 1970's, high world oil prices had given significant impetus to the development of new technologies for the liquefaction or gasification of coal. However, current world oil prices have made these conversion routes economically unattractive as a potential option for Canada.

6.0. PETROCHEMICALS

6.1. Demand Pattern

In 1986, the total requirements for petrochemical feed stocks were 375PJ of which 149PJ came from natural gas, 127PJ from oil and 99PJ from natural gas liquids (NEB, 1988).

The growth in the petrochemicals industry in Alberta was due to the availability of ethane, propane and butane from natural gas production. During the 1960's yields of propane, butanes and pentanes plus increased with increases in the production and processing of solution gas and the implementation of large gas recycling schemes. By the mid 1970's, yields of the propanes, butanes and pentanes plus began to decline. However, the extraction of ethane was just beginning. By 1986, 60 percent of the petrochemical feed-stock demand in Canada was in Alberta, and 60 percent of the total fuel stock requirements was being met by natural gas or natural gas liquids (NEB, 1986).

Eastern petrochemical plants were primarily based on oil derived feed stocks. However, with significant increases in world oil prices during the 1970's, by the early 1980's plants in eastern Canada had increased their ability to switch from oil to ethane, propane and butanes from western Canada.

Most of Canada's capacity is relatively new, world-scale and technically efficient. Four new ammonia plants with a total annual capacity of 800 kilotonnes/year opened in B.C. and Alberta in 1986 and 1987 while two smaller plants in Alberta with a capacity of 160 kilotonnes/year were shut down in 1987. In Quebec, a small ethylene plant (55 kilotonnes/year) was closed at the end of 1986 but a larger plant (200 kilotonnes/year) was modernized between 1986 and early 1988 to permit a much greater degree of feedstock flexibility (NEB, 1988).

6.2. Major Market Constraints

The majority of the enhanced oil recovery (EOR) techniques used in western Canada rely on natural gas liquids for use as miscible fluids. As such, the requirements for miscible fluids are dependent on higher world oil prices necessary to justify the expense of tertiary oil recovery operations.

Ethane currently accounts for 55 percent of the natural gas liquids used in miscible fluids (NEB, 1988). However, over the longer run, ethane demand in Canada should be dominated by petrochemical feed stock requirements.

For Canada to compete in world scale petrochemical markets, it has to have a feed stock advantage to offset the higher construction costs found in Canada and high transportation costs necessitated by a western Canadian location. Therefore, a major constraint to the growth of the petrochemical industry in Canada will be the price of ethane from natural gas versus petrochemical feed stocks derived from oil.

The use of methane for the production of methanol and ammonia also operates under the constraints of cheaper natural gas feed stocks in Canada versus higher capital costs in this country and higher transportation costs to market large volumes of the products.

7.0. NATURAL GAS

7.1. Demand Pattern

During the period 1965-1985, consumption of natural gas increased from 778 PJ to 1763 PJ. The consumption in eastern Canada increased over five times from 35 PJ to 185 PJ, in Ontario it tripled from 256 PJ to 740 PJ and in western Canada doubled from 487 PJ to 838 PJ (Stats Canada).

The demand pattern per customer in the industrial and residential sectors shows a strong substitution of oil with natural gas following the oil price shocks of 1973 and 1978 (see Fuel Substitutability in Different Market Sectors). The demand in the commercial sector increased in the 1970's but decreased later as energy conservation measures were implemented and as the economy entered a recession in 1981.

In terms of percentage of Canadian energy use, in 1965, natural gas provided 13 percent of the final energy demand in Canada. By 1975, it provided 22 percent of the final energy demand, and by 1985, it provided over 25 percent. The industrial sector has historically been the largest consumer of gas utilizing approximately 8 billion cubic metres in 1965 (50 percent of all natural gas usage) and 26 billion cubic metres in 1985 (53 percent of all natural gas usage) (CGA, 1986).

Some of the underlying factors that affected the demand for fuel oil in Canada during the last 15 years (changes in residential and commercial furnace efficiencies, better insulation, new industrial processes and new technology), also had an impact on the demand for natural gas. However, the demand for natural gas was also increased at the expense of fuel oil because of the federal government's Canadian Oil Substitution Program, which was implemented in 1980. To a lesser extent, natural gas was also promoted by the federal government as an alternate motor fuel for automobiles. In addition, the provincial governments of Alberta and Saskatchewan proceeded with rural gasification programs in their respective provinces, and the private utilities extended natural gas distribution systems eastward through Quebec. The use of natural gas as a feed stock for the petrochemical industry also increased significantly during this period.

7.2. Market Constraints

Most new industrial or electrical utility boilers in the U.S. have dual fuel capabilities - some even have triple fuel capabilities. Fuel diversification has intensified competition in the U.S. interfuel market place today even though no "fuel crisis" exists. In addition, during the past dozen years, oil consumption has stayed constant in the U.S., coal consumption has increased 36 percent and natural gas use has fallen by 16 percent.

Years of regulatory interference in both Canada and the U.S., domestic and international politics, and price volatility may have combined to make Canadian sources of natural gas risky in the eyes of American consumers.

Most recently, the precipitous drop in world oil prices has intensified the burner tip competition between natural gas and heavy fuel oil in the U.S. market place.

In addition, there is the constraint of limited or no pipeline access from Canada to certain parts of the U.S. and recent regulatory decisions by FERC in the U.S. which restrict the ability of Canadian producers to pass on certain portions of their transportation costs to U.S. consumers.

Natural gas had been exported to the U.S. in significant quantities since the 1950's and up to the mid 1970's exports ran close to the levels authorized by the NEB. However, from 1975 to 1984, limits were imposed on export volumes and export prices were established by the federal government. Exports to U.S. markets dropped off towards the end of the era, as a natural gas surplus developed in North America. The gas surplus developed as reserve additions greatly accelerated and demand dropped off due to high prices for gas, the effects of conservation efforts throughout the economy, regulatory and political decisions, which prevented exporters from responding quickly to changing conditions, and from 1981 to 1983, a general recession in North America.

As of November 1, 1986, federal government regulations in Canada on export volumes and pricing were resolved and export volumes have increased, but they have only regained the 1970's level of export volumes in 1988 (NEB, 1988). Natural gas prices have been relatively insensitive to world oil price movements since "deregulation" of the gas industry in Canada and North America, primarily due to the over-supply situation.

In Canada, interfuel competition does impose constraints on the increased utilization of natural gas, but interfuel competition is not as intense as in the U.S. Canadian industry, for the most part, does not have the capability to switch fuels as readily as in the U.S. Further, in the residential and commercial sectors, natural gas is generally the preferred fuel for space heating because of its clean burning capabilities, and, subject to the availability of a gas distribution system, the penetration of natural gas supply to Canada's building stock is quite high. In areas where there is interfuel competition with gas, it is with cheap electrical power (Quebec, Ontario and Manitoba). Fuel oil is used for space heating in the Atlantic provinces and in isolated areas of the rest of Canada where the high cost of natural gas transmission would make its use prohibitive.

With deregulation in the Canadian market place, natural gas prices have fallen significantly. However, some gas users are having problems obtaining fair access to gas distribution systems at equitable prices and Alberta has introduced price discrimination for certain end-use markets.

Thus the main constraints to the increased use of natural gas in the industrial, commercial and residential sectors are physical (i.e., lack of distribution networks) and regulatory (i.e., pricing and market access).

The use of CNG as an alternate fuel has several drawbacks. These include lower energy content per unit volume than propane or gasoline and the necessity for the gas to be compressed to high pressures, which increases the costs of compression facilities and the weight of vehicle storage cylinders. The low cost of gasoline does not allow for sufficient savings with the use of CNG to offset the drawbacks.

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FUEL SUBSITUTABILITY IN DIFFERENT MARKET SECTORS

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FUEL SUBSTITUTABILITY IN DIFFERENT MARKET SECTORS

Interfuel competition depends on the substitutability of energy in general (with labour or capital), and on substitutability of different fuels within a given market sector. The evidence concerning the effect of energy consumption on fuel substitutability within different markets is, however, rather mixed. For example, Fuss (1977) found that for the Canadian manufacturing sector coal, gas and oil are moderately substitutable with each other, but that all three fuels are only weakly substitutable with electricity. On the other hand, Halvorsen (1976) found that all four fuels are substitutable in the U.S. manufacturing sector. It is apparent that the role each fuel plays in a different market will depend on: 1) the substitutability of energy with labour and capital in that sector; 2) the price elasticity for energy use and individual fuel use in the sector; 3) the way that growth in that sector affects the demand for energy for different fuels and for interfuel substitution.

The following sections describe the impact that various social, economic, regulatory, environmental and technological factors have on fuel substitutability in Canadian industrial, commercial, transportation, domestic and farm sectors. The effects evaluated include price, real interest rates, government policies, air and vehicle environmental regulations, vehicle efficiencies and other technological factors.

1.0. EFFECT OF FUEL PRICES

1.1. Natural Gas

The effect of prices on natural gas substitutability depends significantly on the type of market. For residential markets, natural gas prices have historically been 50 percent lower than electricity and 25 percent lower than light fuel oil. As a result, the demand for natural gas by the residential sector is less price sensitive.

For the commercial market, natural gas demand is more determined by prices, since the cost of fuel often directly determines the profit. As a result, commercial users are quicker to adapt new energy technologies, and to switch between fuels if it is profitable. For the Canadian commercial sector, natural gas prices have historically been 65 percent lower than electricity prices and 40 percent lower than light fuel oil. However, in Central Canada where prices have been much closer, significant competition and substitutability exist between these fuels.

The largest user of natural gas in Canada is the industrial market. Most of the applications of natural gas are as boiler fuel (in furnaces, kilns, dryers and heaters), and as a direct process heat. In both applications fuel interchangeability between natural gas and refinery products is relatively straightforward and fuel substitution is quite responsive to relative fuel pricing. Historically, natural gas has been priced in the industrial sector at about 10 percent less than heavy fuel oil. With the oil prices shock of 1978, natural gas use significantly increased in the industrial sector (Figure 1), and many forecasters expect natural gas to further increase its share in the industrial market at the expense of light and heavy fuel oil. It is possible that the displaced oil products may find their way into the transportation market.

About 16 percent of the energy used by the transportation sector comes from natural gas (Table 1). This gas is used for pipeline transportation, compressed natural gas and other urban transit uses. It is not expected that the pipeline transmission use could be easily substitutable with other fuels, unless sufficient price differences exist; i.e., diesel or gasoline would have to be priced below natural gas, which is not likely.

1.2. Coal

Over 94 percent of all non-utility coal uses in Canada are by the industrial sector. In these applications, coal has faced significant competition from natural gas in Western Canada, and natural gas and fuel oil in Central Canada. Over the period 1960 to 1986, the coal share of the industrial energy market has declined from 29 to less than 2 percent. To recapture this market, oil prices would have to increase to their early 1980 levels and significant improvement would be required in environmental control technologies for direct use of coal.

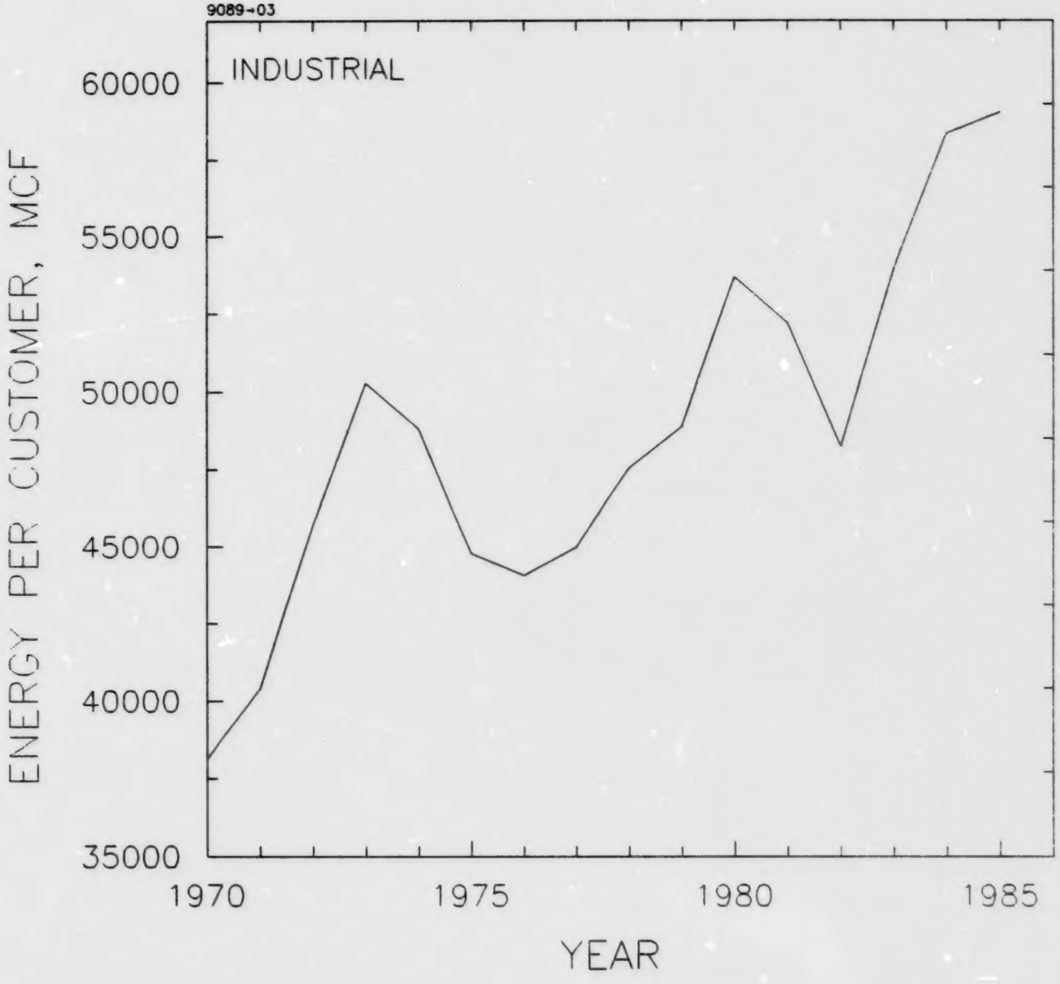

Figure 1. NATURAL GAS CONSUMPTION IN THE INDUSTRIAL SECTOR

Source: CGA (1986)

Table 1. DISTRIBUTION OF END ENERGY USE BY MARKET SECTOR (CANADA, 1986, PERCENT*)

MARKET	COAL	NATURAL GAS	ELECT.	GASOLINE	KEROSENE LIGHT FUEL	DIESEL	HEAVY FUEL OIL	AVIATION GASOLINE
Industrial	3	49	43	--	<0.1	2	3	---
Transport	---	16	2	54	---	18	3	6
Domestic	<0.1	51	42	--	7	--	<0.1	---
Farm	---	23	40	16	3	18	---	---
Commercial	<0.1	52	41	2	2	3	<0.1	<0.1

*Percent of total energy use by the market sector rounded to the nearest percent.

In the utility market, coal, because of its price advantage, is expected to maintain its market, although recently, because of shorter planning horizons, utilities have added increasing numbers of smaller natural gas generation plants for peak and intermediate generation needs. This shift in preferred generation was also partly caused by low natural gas prices, which are not expected to be sustained at the current level in the future.

1.3. **Motor Gasoline and Diesel Fuels**

As of 1986 about 90 percent of motor gasoline use was by the transportation sector, 5 percent by the farming sector and 5 percent by the commercial sector. The percentages for diesel fuel use were 55 percent by transportation, 10 percent by farming, 16 percent by commercial and 19 percent by industry (Table 2).

The demand for gasoline and diesel is not very sensitive to crude oil prices because the cost of crude oil makes up a comparatively small portion of the gasoline and diesel price (about 1/3). On average, a 10 percent change in the oil price might result in a change of 3 percent or less in the gasoline price. For example, the average cost of crude oil in the port of Montreal dropped from $\$246.04/m^3$ in 1985 to $\$143.69/m^3$ in 1987, while the average retail price of gasoline dropped in Quebec only from ¢57.6/liter to ¢50.8/liter. This small decrease in gasoline prices was also

Table 2. DISTRIBUTION OF THE USE OF DIFFERENT FUELS BY MARKET SECTOR (CANADA, 1986, PERCENT*)

MARKET	COAL	NATURAL GAS	ELECT.	GASOLINE	KEROSENE LIGHT FUEL	DIESEL	HEAVY FUEL OIL	AVIATION GASOLINE
Industrial	92	43	45	--	8	19	70	--
Transport	--	5	1	90	--	55	20	81
Domestic	7	28	28	--	67	--	2	--
Farm	--	1	2	5	4	10	0	--
Commercial	1	23	24	5	21	16	8	19

*Percent of total fuel use by EACH market sector rounded to the nearest percent.

due to an increase in taxes on transportation fuels and some distillate fuel oils, in order to maintain tax revenues. As a result, demand for gasoline tends to be less elastic with respect to oil prices.

A similar pattern of price changes and elasticity has been observed for diesel fuels; however, due to a significant price advantage of diesel fuel and higher efficiencies of diesel powered vehicles, significant substitution of diesel for gasoline has taken place over the last twenty years. The diesel to gasoline consumption ratio in Canada has increased from 0.10 in 1972 to 0.22 in 1985 (CPA, 1987). This trend seems to continue into the late 1980's.

1.4. Light and Heavy Fuel Oils

The demand for light and heavy fuel oil is quite sensitive to their prices, their prices in turn have a direct relationship to crude oil prices. A 10 percent change in oil prices would be matched by about the same change in light and heavy fuel oil prices since taxes and refining costs components are a relatively small portion of the end-use price.

The demand for and substitutability of light and heavy fuel oil with natural gas or coal are very much dependent on price differences between the three fuels. Since most of the light fuel oil is used for domestic use (73 percent), light fuel oil has to compete with electricity and natural gas. The significant increase in natural gas use after 1978 was due to oil price shock, which accelerated natural gas substitution of light fuel oil and introduced considerable conservation (see effects of regulatory policies on fuel substitution).

About 70 percent of heavy fuel oil use is in the industrial sector, 20 percent in the transportation sector and 8 percent in the commercial sector (data for 1986, Table 2). As for light fuel oil, following the 1973 and 1978 oil price shocks natural gas captured significant parts of the heavy oil markets (Figure 1). This trend slowed down with the falling oil prices of 1985. In contrast to transportation fuels, taxes on industrial fuels were not increased in 1985, in order to maintain the competitive position of manufacturing industries.

1.5. Electricity

The prime competitors of electricity in industrial, commercial and domestic markets are natural gas and fuel oils, however, only that portion of electricity that is used for space and process heating is a subject of interfuel change. Substitution of electricity with natural gas in residential markets is quite straightforward and determined primarily by the life-cycle costing of both fuels and by the availability of a suitable distribution system.

In industry, electricity is used in process heat applications where precise temperature and process control is required. In this case, although natural gas may have lower life-cycle costing, natural gas equipment may not have the required controllability for the process. Research on development of improved natural gas equipment constitutes a significant portion of GRI research expenditures since it would result in an increased substitutability of electricity with natural gas.

The use of electricity in the commercial sector in applications such as food, etc., is also under strong competition from emerging new technologies using natural gas. As indicated above, the cost of energy often determines the profit margins in the commercial sector, hence the users are quicker to implement fuel substitution if it is profitable.

2.0. EFFECT OF REAL INTEREST RATES

Real interest rates (RIR) can be expected to have a profound effect on fuel substitutability. This effect is, however, often indirect and difficult to quantify. The following discussion exemplifies the direct effect of RIR on fuel prices and, hence, on fuel substitutability in industrial and commercial markets.

2.1. Natural Gas

Real interest rates have a strong effect on the required natural gas well-head price in order to ensure specific field viability. Studies by Adelman et al. (1983) suggest that the RIR determines the value of above-ground (Pa) to in ground (Pb) value of a natural gas pool ($Pa/Pb = 1 - IR/a$, where a = production-to-reserve ratio). If the cost of developing the field is equal, for example, $1.00/GJ then the required well-head price is $1.00 x(Pa/Pb). With an increase in real interest rates, the required natural gas prices are higher and natural gas is less competitive with alternate fuels.

2.2. Oil

Real interest rates would also have a strong effect on the price and supply of crude oil, although the effect in global markets is opposite to the effects shown for natural gas. Marshalla and

Nesbitt (1986) discussed the effect of real interest rates or expectations concerning real interest rates on future world oil prices. They assigned an importance to the level of real interest rates that was equal to the importance that OPEC's degree of co-operation may have on the future world oil market. They conjectured that lowering real interest rates from 6 percent to 2 percent is about equal in magnitude to the effect on oil prices of moving from a competitive oil market (large oil supply) to a market in which oil supply is controlled by OPEC. For a scenario where OPEC exercises market power, an increase in real interest rates from 2 to 6 percent is projected to result in a decrease in oil price from $36/*bbl to $22/*bbl U.S. For a case where there is no OPEC cartel and real interest rates are 6 percent, oil prices are projected to bottom at $14.00/661 U.S. (1987 dollars). Such significant differences in oil prices would, of course, affect pricing of refinery products and would affect the competitive position of oil-derived fuels as discussed in sections 1.3 and 1.4.

2.3. Coal Substitutes

High real interest rates also have a negative effect on the development of fuel substitutes from coal (coal gasification, liquefaction, etc.), and on retrofit of natural gas or oil boilers for coal. In both cases, capital requirements for conversion equipment or plants are high for coal-derived fuels. Capital payouts for coal fuels often constitute more than 50 percent of the levelized cost of the fuel, which means that an increase in the real interest rate results in a disproportionately high increase in the energy price.

The impact of high interest rates and high equipment costs can be illustrated by the lack of increase in coal use in Western Canadian industry in the early 1980's despite high natural gas prices at that time. A quite large price difference between the two fuels (about $2.80/GJ for natural gas and $1.40/GJ for coal), was not sufficient to encourage large users to switch to coal. High interest rates and, hence, the high discount rates applied, made such a substitution unattractive.

The persisting high real interest rates and future price uncertainty for natural gas and oil have resulted in industry resisting any fuel substitution to coal. The general strategy seems to be to run down the existing equipment until it requires replacement, rather than to lay out additional capital before the life-cycle of the existing equipment is completed.

3.0. EFFECT OF REGULATORY POLICIES

Regulatory policies most often affect fuel substitutes indirectly. They influence taxation, establishment of export quotas, etc. Sometimes, however, regulatory policies have a direct impact on fuel substitution. Regulatory policies can provide for the development of programs that compensate users for retrofit cost (e.g. "off-oil" program) or restrict the use of targeted fuel (restriction on use of natural gas for electricity generation in the U.S.).

3.1. Natural Gas

In 1980 NEP introduced several regulatory plans for fuel substitution in Canada. These plans included: 1) the Canadian Oil Substitution Program (COSP) which provided grants of up to 50 percent of the cost of converting from oil to alternative systems such as natural gas or electric heating, or wood heating equipment incorporating increased efficiency; and 2) the Canadian Home Insulation Program (CHIP) which provided grants towards the cost of insulating homes built before 1981. Both programs resulted in more efficient energy use in the residential market and increased use of natural gas in Central Canada.

In addition, during the last two decades, other provincial and federal regulatory policies affected fuel substitution, fuel pricing and cross subsidization of different energy markets.

These effects are, however, less quantifiable and not as telling as those of the programs described above. In general, most regulatory policies affected market pricing and relative competition of targeted fuels indirectly.

4.0. EFFECT OF TECHNOLOGICAL CHANGE

4.1. Natural Gas

Fuel substitutability is governed by its life-cycle costing, which includes fuel price and efficiency, and by the cost of facilities including their expected operating and maintenance cost. Increases in fuel price are often counteracted by development of a more efficient technology, which would permit the maintenance of the fuel's market share. Examples of such strategies can be seen in the Gas Research Institute's (GRI), research plan aimed at offsetting the anticipated increase in natural gas prices through development of high efficiency industrial equipment that would permit natural gas to maintain its share of the industrial market (Linden, 1986). This strategy is also designed to permit higher priced natural gas from the lower 48 states to compete with electricity and distillate oils in the residential, commercial and high-form value industrial markets.

In search of new, high-form value, large volume markets, GRI also pursues technology development in areas such as combined cycle power generation, gas-enhanced sulphur oxide and nitrogen oxide emission control for utility boilers, or low-investment cost fuel cells. GRI's technology development strategy for increasingly efficient use of natural gas calls for a 50% increase in present residential efficiency and a several-fold increase in industrial efficiency.

In order to increase the use of natural gas in commercial and industrial markets presently dominated by electricity, GRI also looks at development of technology that will increase the controllability of natural gas equipment as well as its convenience and ease of installation. The development of gas fueled cooling equipment for the residential and industrial sectors presents a challenge.

The overall technology development strategy of GRI is to move natural gas uses from low-form value markets such as boiler fuel to higher-form value markets such as residential, commercial and selected industrial uses. A next step in this strategy would be to target even a higher-form value market, i.e., the transportation sector. This approach is not only aimed at developing new markets for natural gas, but also at accommodating the higher natural gas well-head prices expected in the future.

4.2. Motor and Diesel Fuels

An approach similar to the development of more efficient natural gas equipment has been pursued by automotive manufacturers who have developed more efficient and smaller internal combustion engines. The efficiency of an average new vehicle in North America has increased from about 16 miles per gallon in 1974 to 29 miles per gallon in 1986 (Figure 2). The efficiency of all vehicle stock has increased to about 23 miles per gallon. This

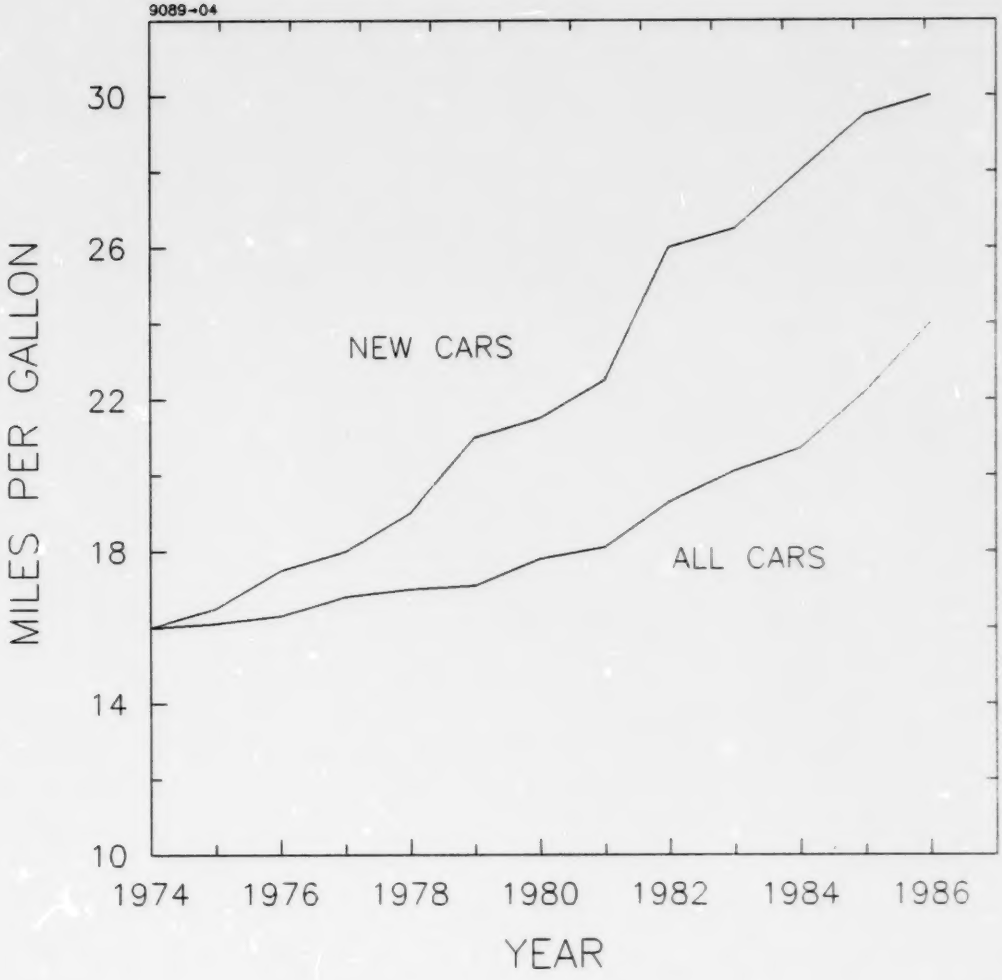

Figure 2. MOTOR VEHICLE EFFICIENCY IN THE U.S.

Source: CERI (1988)

figure reflects the time required for replacement of the old stock with more efficient and smaller cars and trucks.

Another example of the effect of oil price shock and technological improvements has been the consistent growth of light duty diesel powered vehicles since the early 1970's. The increased use of diesel vehicles had been driven by the higher fuel efficiency of diesel engines (about 20 percent higher than gasoline engines) and by the fact that historically, diesel fuel has been priced lower than gasoline. Further incentive for increased diesel fuel use has been the U.S. Federal Corporate Average Fuel Economy Requirement legislation which set an overall average efficiency for new vehicles at 27.5 miles per gallon for 1985. Introduction of more fuel efficient diesel-powered vehicles has been one of the strategies adopted by the auto manufacturers to meet the federal requirements.

The future increase in the use of diesel fuel is limited by the current refinery product range or, specifically, by the demand for middle-distillate fuels. North American refineries have an average ratio of gasoline to middle-distillate fuel production of about 16:10 (about 11:10 for Canada in 1986; CPA, 1987). The middle-distillates include diesel fuel, kerosene, jet fuel and heating oil. The ratio of gasoline to middle-distillate could be potentially reduced to 7:10, but beyond this, it may not be economic or energy efficient (Lawrence et al., 1980). In essence, the technology used by the refiners and the market demand for distillate fuels determine a practical limit on diesel fuel production.

Another limit on increased diesel use is the decline of diesel fuel quality. In the last decade and a half, there has been a gradual decrease of the average quality of diesel fuel, i.e., lower cetane number, higher aromatic hydrocarbon contents and higher sulphur content in the diesel. This has posed serious environmental and health concerns about the use of diesel fuel in urban areas.

Where fuel properties do not vary significantly from the specifications for gasoline-engine stock, a number of different substitute fuels and motor gasolines are possible. Examples are gasohol, different types of gasoline including different octane enhancers, compressed natural gas (CNG), etc.

In countries like New Zealand, Argentina and Brazil, compressed gas plays a significant part in overall national energy policies. The advantages of converting to CNG are: 1) reduction in operating cost where natural gas prices are low; 2) high-octane characteristics (130 CNG vs 95 for super-grade gasoline); 3) clean and more regular combustion, longer engine life; and 4) possible substitution to diesel by using a mixed fuel with 30 percent diesel substitution, pilot injection with 80 percent diesel substitution, and full auto conversion of diesel engine by addition of spark ignition. The main technical disadvantages are the size and weight of the tanks required, and the small operating range and slightly lower power of a CNG engine.

The effect of gasoline engine design on the required substitute fuel characteristics exhibits itself in terms of the demand on octane, volatility and fuel quality. Most gasoline engines are designed to operate on 87 octane fuel. For higher performance engines, premium unleaded gasoline offers the required 95 octane. With leaded gasoline being phased-down, the required octane number of unleaded substitutes can be maintained by: 1) alkylation, isomenzation or more severe refining, or 2) the addition of octane enhancers such as oxygenates or aromatics. Depending on the source of feedstocks and refinery plant design, different approaches to octane enhancers may be feasible.

For oxygenates, MTBE, methanol and ethanol are the most commonly used additives. The gasoline engine performance is not affected by oxygen content of up to 3.7 percent (w/w), which means that up to 5 percent (v/v) of methanol, and 10 percent of ethanol (v/v) can be added without adversely affecting engine performance. Oxygenate concentration above that limit could result in poor performance. The oxygenates are acceptable at specified concentrations provided that the necessary cosolvents and corrosion inhibitors are added (Baker & Chui, 1986). For engines designed for low-lead gasoline (pre 1975), alcohol substitutes are not acceptable and MTBE can be used as a gasoline component to increase octane number.

The other fuel characteristic that is important to gasoline substitutability for current motor vehicles is volatility. Minimum gasoline volatility is needed for starting at low temperatures; however, high volatility during summer months may cause a "vapor lock" and stall the vehicle. The historical trend has been towards increased fuel volatility as refiners increased conversion to light ends to meet the required lead phase-down. The volatility of market gasoline increased from 9 psi in 1970 to about 10.5 in 1986 in the U.S. (Jones & Watters, 1988). The trend toward an increased number of fuel injection engines makes high volatility a lesser problem since fuel injection engines are more tolerant of high volatility during drive conditions; however, other issues such as vapor-lock and hot fuel handling of vehicles, and fuel quality required to minimize deposit formation in the power train system remain as tight constraints on fuel substitutability of gasoline.

Fuel substitutability within the transportation sector seems historically less price sensitive and more driven by other considerations such as perceived availability of fuels, geographic allocation and distribution, and standardization of the supply methods and fuel characteristics. Only large users of transportation fuels who are operating vehicle fleets and are capable of developing their own distribution system seem to respond to the fuels pricing within a short time frame. For most users, who represent a large stock of existing vehicles, the change to different fuels is gradual and slow.

5.0. EFFECT OF ENVIRONMENTAL CONSIDERATIONS

5.1. Coal

Coal has been affected by environmental regulations more than any other fuel. Regulations affect both the demand for coal and its utilization and also influence its effectiveness as a substitute for other fuels. In its major use as an industrial fuel, coal faces constant interfuel competition from natural gas and heavy fuel oil. Coal has lost already a significant part of the industrial market. In 1950 coal held over 30 percent of the industrial energy market; in 1986 it held about 2 percent of the market. This was primarily due to competitive life-cycle costing of natural gas, refinery products and electricity. In the late 1970's, coal experienced a resurgence prompted by high oil and regulated gas prices; however, increasing environmental concerns and more stringent environmental regulations are perceived as seriously dampening any price advantages held by coal.

Similar strict environmental constraints have been implemented for coal utilization in the utility market. In 1971 and 1979 the government of Canada introduced air emission guidelines, aimed at reduction of particulate, and sulphur and nitrogen oxides emissions from utility sources. The guidelines require that emissions be less than 43 ng/J for particulate matter, 258 ng/J for nitrogen oxide and 258 ng/J for sulphur dioxide. This means that almost all new power plants would require particulate control equipment, and some strategy for sulphur dioxide and nitrogen oxide control. The amount of sulphur which must be removed would vary from 40 to 60 percent, and higher, for Western Canadian coals and up to 90 percent for U.S. coals burned by Ontario Hydro. The percent emission guidelines for NOx can be met by the existing, low cost, advanced combustion technologies; however, any further reduction in NOx would require much more expensive control technologies.

Increased environmental concerns and regulation make coal burning much less attractive than burning natural gas or developing small hydro sites. Table 3 depicts the number of generating units operated between 1980 and 1987. The number of hydro units increased by about 10 percent, gas turbine units by 24 percent, while the number of coal units remained almost unchanged. Most of the new capacity added was in non-coal generating stations. (Note: It could be argued that the major reason for increase in hydro and natural gas units was strategic, i.e., in times of uncertain growth of electricity, utilities opted for construction of smaller hydro and natural gas plants). Table 3 also shows a drastic decrease in diesel generating units due to increased cost of diesel fuel in the 1980's.

5.2. Motor Gasoline and Diesel Fuels

Several environmental considerations have influenced the characteristics and fuel interchangeability of gasoline and diesel fuel in the last two decades. Perhaps the most

Table 3. NUMBER OF ELECTRIC GENERATION UNITS IN CANADA

YEAR	HYDRO	COAL	DIESEL	NUCLEAR	NATURAL GAS
1980	467	93	N/A	8	66
1981	470	91	N/A	8	63
1982	483	94	39	8	78
1983	488	94	31	11	82
1984	488	92	35	13	82
1985	490	85	34	15	80
1986	508	86	33	17	82
1987	517	91	20	18	82

Hydro: 24 MW or longer
Coal: 60 MW or longer
Nuclear: 200 MW or longer
Diesel and Natural Gas: 1 MW or longer

Source: CEA, 1988

significant one was the gradual phase-down of leaded gasoline with the federal government deadline for a total ban on leaded gasoline as of December, 1990. This was achieved by increasing the refinery severity or throughput, or the addition of isomerization units, or by the addition of alcohols or MTBE blends to enhance the octane number of unleaded gasoline. The switch from leaded to unleaded gasoline resulted in a change in particulate emissions from vehicles. In the case of leaded gasoline, which contains about 0.2 g/litre of tetra-ethyl lead, about 95 percent of lead was exhausted in the form of submicron particles. Exhaust emissions from unleaded gasoline contain particulate concentrations about 50 times less than that of leaded gasoline. These particles are made up primarily of carbon and trace metal impurities present in the gasoline (Cuddihy et al., 1984).

It seems, however, that phase-down of lead did not result in significant interfuel substitution. The change in refinery operations resulted in increased crude requirements but not enough to significantly increase gasoline prices. Also, the use of alcohols in gasohol was more the result of oil price shock in 1978 rather than phase-down of lead.

A substantial increase in use of diesel fuel in light-duty vehicles over the last decade has raised concerns about the health risk posed by diesel fuel emissions. Emissions of particles, nitrogen oxide, carbon monoxide and hydrocarbons are typically on the order of 10 to 100 percent higher from diesel powered vehicles than from gasoline powered vehicles (Table 4). This is despite substantial technical effort made by automotive manufacturers to reduce those emissions.

The most serious emissions are particles and hydrocarbons. Diesel exhaust particles consist of aggregate carbon microspheres coated with a variety of organic compounds. These compounds have been identified as potentially carcinogenic. Hence, there is a perceived increased degree of risk of lung cancer due to diesel fuel exhaust (Cuddihy et al., 1984).

Diesel exhaust also contains gaseous pollutants such as sulphur and nitrogen dioxides, and hydrocarbons. These emissions are about twice the level of emissions from gasoline and are of possible concern in the future. If emission control devices will be required on diesel power vehicles in the future, we could expect a 5 to 20 percent reduction in diesel fuel efficiency, which is similar to the reduction of motor gasoline efficiency when pollution control equipment is installed (Considine, 1977). Such a reduction in diesel efficiency would eliminate the advantages of diesel vehicles and decrease the attractiveness of diesel engines as substitutes for gasoline engines.

One of the possible fuel substitutes for reduction of diesel emissions is the use of "neat" methanol. Exhaust from neat methanol does not contain any soot or particulates and the NO_x level is about half of NO_x emissions from diesel. Methanol

Table 4. TYPICAL VEHICLES EMISSIONS (grams/km)

	PARTICLES	NITROGEN OXIDES	CARBON MONOXIDES	HYDRO CARBONS
Light-Duty Diesel	0.1 - 0.4	0.5 - 2	0.5 - 3	0.05 - 0.8
Light-Duty Gasoline	0.001 - 0.004	0.2 - 1	1 - 3	0.08 - 0.5
Heavy-Duty Diesel	0.5 - 4	3 - 20	5 - 50	0.9 - 6
Heavy-Duty Gasoline	0.004 - 0.2	1 - 11	10 - 200	2 - 20

Source: Cuddihy et al., 1984

energy content is about half that of diesel fuel, however, methanol has 10 to 20 percent better energy efficiency than diesel fuel.

Additions of oxygenates (methanol, ethanol, MTBE) to gasoline has a number of beneficial environmental effects (Table 5). However, alcohols also result in an increase in evaporative emissions by increasing RVP by 2 to 3 psi. The latter is of special concern at higher elevations where increased emissions of hydrocarbons combined with increased NO_x emissions result in an increase of ambient ozone concentrations in summer. In winter, the use of alcohols has a minute effect on evaporative emissions but a significant beneficial effect on exhaust emissions.

Table 5. EFFECTS OF OXYGENATES BLENDS ON VEHICLE EMISSIONS (percent change vs gasoline fuel)

TECHNOLOGY	2.0% OXYGEN			3.7% OXYGEN		
	CO[1]	NO_x	HC[1]	CO[1]	NO_x	HC[1]
No Catalyst	-13.2	+2.1	-3.0	-24.5	+3.8	-5.5
Open-Loop Catalyst	-18.9	+2.2	-8.4	-34.9	+4.0	-15.6
Closed-Loop Catalyst	-11.6	+4.4	-2.8	-21.4	+8.1	-5.1

[1] same RVP

Source: U.S., E.P.A. 1988

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OPPORTUNITIES AND CONSTRAINTS FOR NATURAL GAS CONVERSION TECHNOLOGIES IN THE ENERGY FIELD

OPPORTUNITIES AND CONSTRAINTS FOR NATURAL GAS CONVERSION TECHNOLOGIES IN THE ENERGY FIELD

1.0. INTRODUCTION

The perception of Canadian energy reserves and markets has undergone significant change in the last two decades. The oil price shocks of 1973 and 1979 provided the impetus for technological changes and the implementation of conservation measures which have resulted in significant improvements in Canada's energy use. Perceived energy shortages, the control of world oil markets by OPEC and substantial increases in the value of Canada's energy resources encouraged a much greater degree of direct government involvement in the energy sector of the economy at both provincial and federal levels. Governments also placed much more emphasis on research and development efforts to develop alternate energy sources and new or better technologies for the production of conventional energy forms.

The post-1980 energy market environment differs dramatically from the previous decade. There has been a large oversupply of oil in world markets and OPEC has a much diminished market position. Natural gas supplies in the North American market have exceeded demand since the early 1980's. As a result, both oil and gas prices have dropped significantly. However, the sustained drop in oil and natural gas prices does not appear to have stimulated a major trend toward increased energy usage in Canada.

Coincident with the 1980's oversupply of oil and gas and the drop in prices for these commodities, there has been a lessening of governmental regulation and control of the energy sector. Also, a much greater public awareness of the environmental impacts of energy production and consumption on a global basis has developed. This has resulted in an increasing emphasis by governments on the public safety and pollution control aspects of energy projects and energy consumption.

Energy requirements in Canada today are being supplied from a multiplicity of sources with less reliance on oil and increased reliance on natural gas, electricity and coal. The Canadian energy market is basically deregulated interprovincially and for the most part the energy sector already operates in a free-trade environment with the United States.

In the period 1965 - 1985, Canadian reserves of marketable natural gas more than doubled from 40 EJ to 84 EJ, whereas established conventional crude oil reserves decreased from 36 EJ to 24 EJ (Figure 1). The total technically recoverable resources (reserves assessed without regard for their economics) were estimated in 1987 at 205 EJ for natural gas and 176 EJ for conventional crude oil (NEB, 1988).

The shift between crude oil and natural gas resources is even more pronounced when one compares reserves-to-production ratios and their respective share of Canadian energy demand. Since 1965, the reserve-to-production ratio (total reserves over current annual rate of production) has decreased from 30 to 13

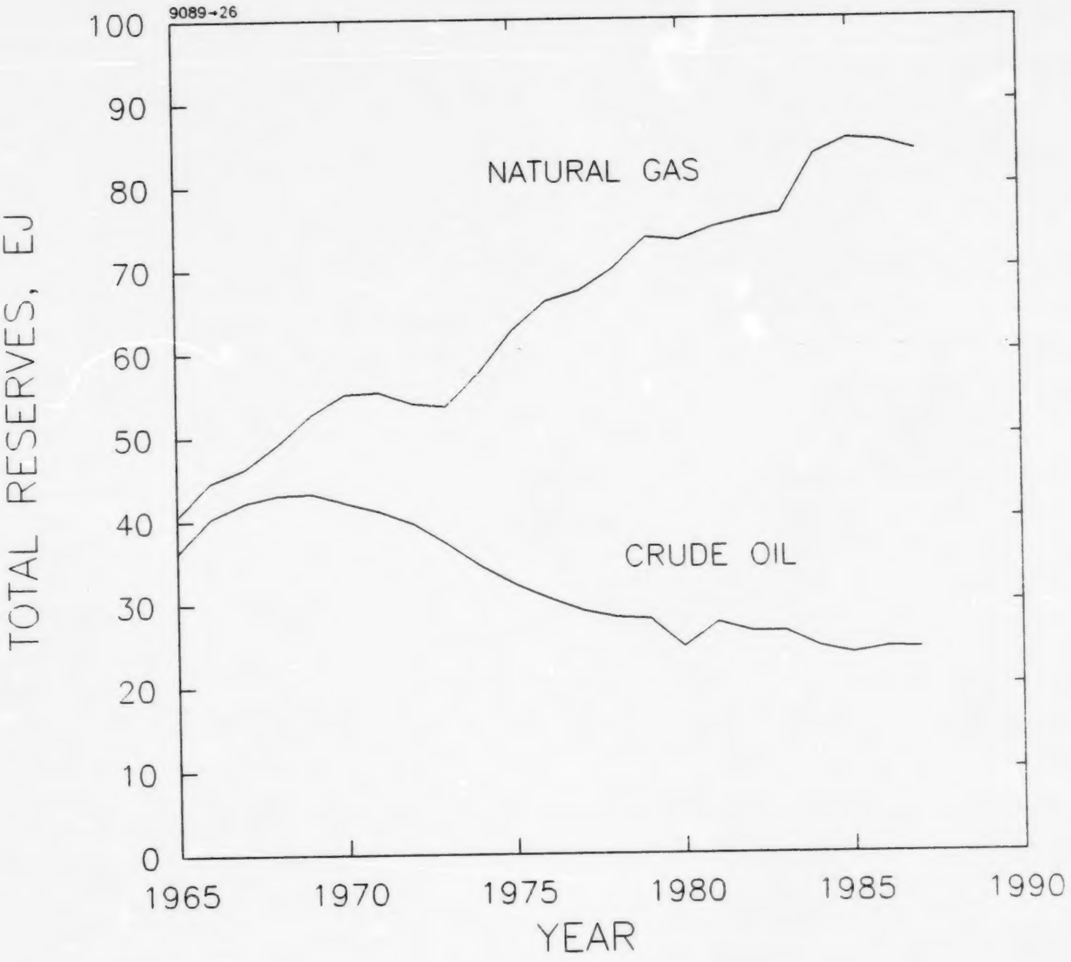

Figure 1. REMAINING CANADIAN ESTABLISHED CRUDE OIL AND NATURAL GAS RESERVES

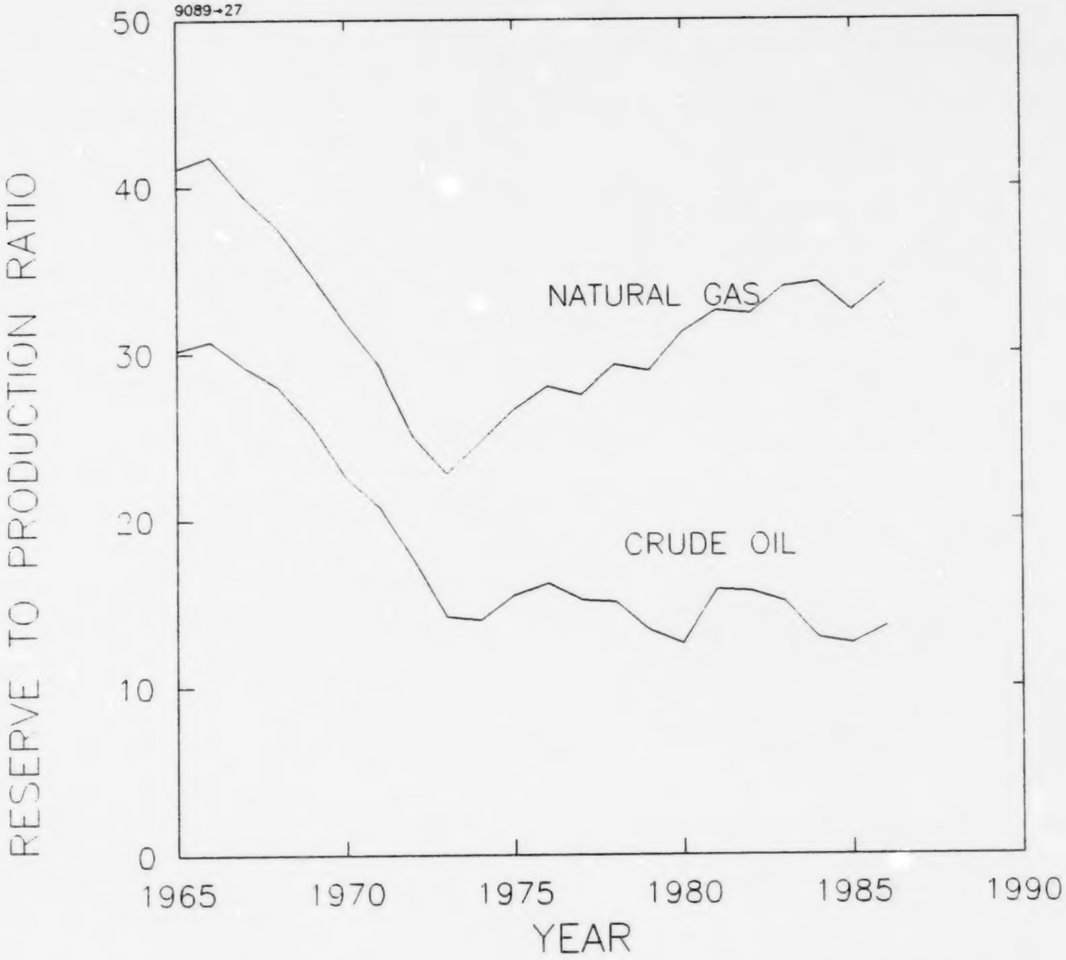

Figure 2. RESERVES-TO-PRODUCTION RATIO FOR ESTABLISHED CRUDE OIL AND NATURAL GAS RESERVES

for crude oil whereas for natural gas the ratio decreased to the low 20's in the early 1970's and then increased to 34 in the 1980's (Figure 2). The Canadian crude oil market share has decreased from 55 percent in 1965 to 40 percent in 1985, whereas the market share for natural gas has increased from 18 percent to 25 percent, during the 1965 - 1985 period.

During the last two decades, oil has been increasingly dedicated in Canada to transportation use. For example, over 63 percent of the 1985 crude consumption was slated for the production of transportation fuels. The high reliance of the transportation sector on crude oil has, however, made it vulnerable to fluctuations in world supply and prices of crude oil. As a counterbalance to this vulnerability, the large Canadian gas reserves can be viewed as a potential source of future transportation fuels. The reserves and production capacity of natural gas are more than sufficient on an energy equivalent basis to meet the Canadian transportation fuel demand. However, the present technological and economic constraints in the direct use of natural gas in vehicles (NGV) or the conversion of natural gas to transportation fuel substitutes or components, impede a wide use of natural gas. The nature of these constraints and how they may be eliminated, are discussed in Section 2 of this paper.

Canada has two other fossil fuel resources which are amenable to conversion to transportation fuels: 1) bitumen resources which are estimated at over 195 EJ of established reserves; and 2) coal resources which are estimated at 200 EJ of reserves of immediate interest. In 1987, the production of synthetic crude from bitumen reached 654 PJ (17 million cubic metres) or about 20 percent of total Canadian oil production. The projected production of synthetic crude from bitumen is 750 to 950 PJ for 2005 (NEB, 1988).

There is no commercial production of transportation fuels from coal in Canada, despite much interest in coal conversion during the late 1970's. The high cost of coal-derived transportation fuels, the long time required for development of improved technologies, and a sharp drop in world oil prices in the mid 1980's all contributed to the postponement of development plans for coal conversion plants.

In the period 1965 - 1985, natural gas also became an important raw material for production of transportation fuel components, or chemicals such as methanol, hydrogen and ammonia. Over 65 percent of the Canadian volume of these chemicals was produced in 1987 via reforming and partial oxidation processes using natural gas as feedstocks. Near-term market projections call for an increase in the use of natural gas for production of methanol for an end-use as fuel components (neat methanol or MTBE), and for production of hydrogen for bitumen and heavy oil upgrading. The present markets and technologies for conversion of natural gas to fuel substitutes or components are discussed in Section 2.5.

2.0. PRESENT USE AND TECHNOLOGY

Since the end of 1985, the domestic market for natural gas in Canada has been moving towards the development of a market-oriented pricing regime wherein the marketplace is to determine the supply, demand and price of natural gas.

In 1987 about 89 percent (1697 PJ) of Canadian natural gas consumption was for direct use in the residential, commercial and industrial sectors, and 11 percent (210 PJ) was used for the production of chemicals and fuel components. The thermal use consisted of 781 PJ (41 percent) for industrial consumption, about 475 PJ (25 percent) for residential and agricultural use, and 342 PJ (18 percent) for commercial use. The breakdown of the natural gas use for chemicals and fuel components (210 PJ) included 80 PJ (estimated) of natural gas equivalent for methanol production, 40 PJ natural gas equivalent for hydrogen production for synthetic crude, 17 PJ of natural gas equivalent for refinery hydrocracking, and the rest for hydrogen production for ammonia and other chemicals.

The total indirect use of natural gas as transportation fuel components (H_2) and fuel substitute (methanol) was approximately 57 PJ or about 3.0 percent of the natural gas consumption.

The following sections review the present use and technology for natural gas in residential (including agriculture), commercial and industrial markets. The review addresses potential technological improvements and opportunities for growth in natural gas consumption in each end-use area. The focus of the review is, however, on transportation fuel components and substitutes including the direct conversion of natural gas to methanol and higher hydrocarbons.

2.1. Residential and Agricultural Sector

The residential market includes the urban domestic and farm sectors of the Canadian economy. The main uses for energy in this sector are for space heating, water heating, lighting and appliances.

In 1987 the total residential and agricultural energy demand was 1239 PJ of which 475 PJ was supplied by natural gas, and 428 PJ by electricity. The remainder was supplied by light heating oil, kerosene, natural gas liquids, etc. The number of natural gas customers was over 3 million and on average natural gas use per customer was about 4 thousand cubic metres (CGA, 1986).

Interestingly enough, although the number of natural gas customers significantly increased during the last two decades (from about 1.4 million in 1965), the consumption of natural gas per customer has remained almost the same (CGA, 1986). Despite larger incomes per family and bigger homes, the increased efficiency of space heating equipment and improved conservation through better insulation of houses helped to maintain the natural gas consumption per customer virtually constant.

The demand pattern for residential space heating has shown a significant substitution of oil with natural gas following the oil price shocks in 1973 and 1978. This was primarily due to government programs and incentives to switch from oil to alternative fuels and to increase building insulation levels. The trend towards more energy efficient houses is expected to continue. However, for natural gas to increase its share of the residential energy market, it would have to compete more effectively with electricity by maintaining its competitive pricing and through the development of improved space heating and air conditioning appliances. This should be possible to achieve since in the residential market, natural gas has historically been priced 50 percent lower than electricity.

Analysis of the residential energy market shows several interesting features:

a) customers have become more knowledgeable and sophisticated in their energy purchase decisions.

b) decisions are increasingly based on life-cycle costing of alternative fuels and equipment.

c) higher initial costs for high efficiency equipment became acceptable to customers providing that lower fuel costs would yield payback periods of about three to five years.

Since residential energy demand is expected to grow more slowly in the next two decades (about 1.2 percent), an increase in natural gas use can come only if natural gas captures a larger portion of the residential market share. A number of R&D initiatives are being pursued by gas producers and equipment manufacturers to improve the attractiveness of natural gas. The main foci of this development are:

a) increased efficiency of natural gas appliances such as high efficiency and low cost residential furnaces and water heaters, achieving 85 and 96 percent efficiency, respectively, vs conventional appliance efficiency of less than 80 and 90 percent.

b) further reduction in the cost of advanced equipment such as pulse-combustion furnaces, etc.

c) development of methods for low-cost piping and improved natural gas metering technology.

d) development of small-space cooling, desication and conditioning equipment, including small cogeneration units.

The NEB projects an increase in Canadian residential energy demand to 1570 PJ by the year 2005. We believe that natural gas will maintain its current share of the residential market of about 40 percent through the introduction of new and improved natural gas space heating and air conditioning equipment. However, it is critical that the current price ratio of electricity to natural gas be maintained in the future. If not, natural gas may find it hard to compete with the convenience of electricity.

2.2. Commercial Sector

The commercial market includes institutional customers and service industries. The main uses for energy in this sector are similar to the residential sector, and the competition between natural gas, electricity and fuel oil in the various regions of the country is also very similar.

During the past two decades, the number of commercial natural gas customers increased from 130,000 in 1965 to over 340,000 in 1987. The total energy consumed in 1987 was 956 PJ of which 342 PJ was supplied by natural gas 345 PJ by electricity and the remaining by refinery products.

The annual sales of natural gas per customer increased from 28,000 cubic metres in 1965 to 38,000 cubic metres in the late 1970's and then decreased to about 33,000 cubic metres in the 1980's. The large increase in efficiency of utilization of natural gas in the 1980's reflects increased conservation measures and improved gas equipment, implemented in response to increased oil and natural gas prices.

For the Canadian commercial sector, natural gas prices have historically been 65 percent lower than electricity prices and 40 percent lower than light fuel oil. However, in central Canada where prices have been much closer, significant competition and substitutability exist between these fuels.

In order to increase the use of natural gas in commercial applications, which are presently dominated by electricity, gas equipment manufacturers have undertaken development of a series of advanced gas equipment for gas fuel cooling, cogeneration for commercial application, gas ranges and other appliances for restaurants and fast food outlets, etc. We expect that as the Canadian economy becomes increasingly more service oriented, commercial energy markets will offer a number of new opportunities for natural gas applications. The NEB projects an increase in commercial energy demand to 1050 PJ by the year 2005, or about a 1.2 percent increase in demand per year. This would entail some increase in efficiency of energy utilization in the commercial sector with natural gas maintaining its share of the commercial market.

2.3. Industrial Sector

The industrial sector includes manufacturing, forestry, construction and the mining industry. It does not include the petrochemical industry.

2.3.1. Manufacturing

In 1987, the demand for energy by the manufacturing sector was about 1734 PJ, which included iron and steel product treatment, smelting and refining of metals and other finished products, and materials heat treatment requirements. Natural gas provided about 723 PJ of the energy required and electricity supplied 581 PJ. Each of the two fuels surpassed the oil market share in manufacturing energy demand in 1981 and have become the main competitors in the industrial energy market since.

The response of the gas industry and of equipment manufacturers to an increased market share of electricity has been the development of less costly, more efficient burners and furnaces, based on high technology materials and advanced electronic controls. The following are examples of some of the equipment developments and improved uses of natural gas in the manufacturing sector.

Heat Treating

An increased demand for high tech, high performance steels, alloys and ceramics has also created new opportunities for heat treatment technologies and equipment. As a result, gas equipment manufacturers developed advanced gas burners and furnaces capable of operating at above 1100°C, at thermal efficiencies better than 70 percent. The furnaces provide uniform temperature and high radiation heat flux by means of high temperature, radiant tube burners which are designed for up to 1230°C tube surface temperatures. The burners can provide temperature control within ± 15°C, which is equal in performance to electric furnaces. High temperature, uniform heating, good controllability and high durability result in increased productivity of the furnace.

New furnaces also offer controlled-atmosphere heat treatment with a 15 percent increase in energy efficiency and an expected cost reduction of 25 percent, in comparison with the existing nitrogen-methanol generator systems. The furnaces also have other advantages, such as faster warming up time, which make them more productive.

We expect that as the demand for more precision heat treatment increases, natural gas will maintain its current share of the heat treatment market, although some give and take is possible between natural gas and other fuels such as electricity.

Boilers

Natural gas is the fuel of choice for industrial boilers with 1987 consumption estimated at over 300 PJ versus estimated heavy fuel oil consumption of 100 PJ. The challenge that natural gas faces in maintaining its market share comes from coal, particularly with new heavy oil and bitumen production in western Canada. Natural gas is also vulnerable in dual fuel boiler markets if low oil prices continue. As natural gas prices become decoupled from oil prices and increase to reflect the cost of reserves addition, some of the users may switch to oil. In order to counteract such a possible scenario, the gas industry has identified several areas of development, for example:

a) to improve efficiency of natural gas boilers by a scale-up of pulse combustion technology.

b) to improve design and efficiency of economizers and air preheaters.

We do not expect that natural gas will lose its share of the boiler market, even though natural gas use will return to more balanced supply and demand. Expected future increases in the environmental cost of burning coal and heavy fuel oil may more than offset increasing gas prices. Also, continued improvements in the efficiency and performance of gas boilers are expected to help to maintain natural gas' share of the industrial boiler market.

2.3.2. Mining

In 1987 the Canadian mining industry consumed over 231 PJ of energy of which natural gas contributed about 23 percent (53 PJ). Mining, including enhanced oil recovery and bitumen mining, will likely be the fastest growing industrial energy market in the next two decades. Just for bitumen mining, the NEB projects an increase of 150 PJ to 320 PJ in energy needs between now and the year 2005. The two fuels which are expected to compete for this market are natural gas and coal.

A significant increase for natural gas demand can also be expected for enhanced oil recovery and heavy oil recovery. The largest increase would take place in the western Canadian and California markets. The sizes of these new markets is difficult to assess since they would depend on oil prices, technology, reserves employed in recovery and other factors.

2.4. Utility Sector

In 1987 only 3 percent (55 PJ) of Canadian gas consumption was used for power production. This amount was used equally by utilities and industry.

Historically, the majority of utility natural gas use was for peaking power, using gas turbines. The advantages offered by gas turbines include low cost for the capacity (about half of the coal fired plant capacity cost) and short lead time required for construction. In provinces close to gas production, gas turbines offer an ideal peaking fuel.

The trend seems to be changing, however, as utilities begin to consider using natural gas in repowering for increased capacity, cofiring for decreased pollutants emission and cogeneration for increased fuel cycle efficiency. This trend evolved as a result of several factors:

a) difficulty with predicting the electrical growth due to uncertainties in economic and regulatory factors forced utilities to build smaller, shorter lead time plants, loosening the economy of scale of larger coal or nuclear plants.

c) new coal fired plants increased in price because of the environmental control requirement on plant emissions.

c) nuclear power plants have come under criticism because of escalating cost, and investor as well as public reluctance to support such developments.

d) the number of available, potential hydro sites has decreased.

The opportunities for increased use of natural gas are especially bright for cogeneration and combined-cycle plants.

Natural gas combined-cycle power plants offer several advantages to utilities. First, efficiencies as high as 40 to 45 percent may be achieved. Second, the plants can have modular construction, allowing the addition of capacity as it is needed, in a shorter time. The combined-cycle plant can be located near urban centers, thus closer to the load, since little stack or other pollution is generated.

It is estimated, that with natural gas prices remaining low, combined-cycle gas fired power plants could account for 10 to 30 percent of new electric capacity addition. Based on the NEB projection for the Canadian electric capacity addition of 170 terawatt hours between 1986 and the year 2005, the new demand for natural gas would range from 61 to 183 PJ.

Electric market analysis also indicates that cogeneration for steam-electricity and direct heat-electricity applications could constitute a growth market for future use of natural gas. Cogeneration, at $650/kw and a 2 to 3 year lead time, compares very well with $1400 to $1600/kw and an 8 year lead time for coal power plants.

Cogeneration has already become a preferred energy conversion method where thermal and electric loads are well matched. With further deregulation of utility operations and access to transmission facilities, one could envisage a number of industrial players entering cogeneration for their own use and for sale. It is difficult to estimate new cogeneration capacity, but if 10 percent of industrial electric energy needs were cogenerated, this would be equivalent to 67 PJ of natural gas in 1987.

2.5. Transportation and Other Sectors

The transportation sector includes road, rail, air and marine transport.

In 1987 the total transportation sector energy demand was 1709 PJ with 1579 PJ supplied by oil, 96 PJ by natural gas and 34 PJ by natural gas liquids and electricity. The direct use of natural gas was mainly for compression and transport of natural gas in transmission lines.

In 1987 about 200 PJ of natural gas was also consumed in the production of chemicals and fuel components such as methanol or hydrogen for bitumen upgrading, i.e., about 80 PJ of natural gas for methanol production and 40 PJ for hydrogen production for synthetic crude (Figure 3).

The following section discusses the applications and technology for natural gas conversion to transportation fuels or fuel components.

2.5.1. Natural Gas Vehicles (NGV)

The increase in gasoline prices in the late 1970's prompted a number of pilot projects in Canada on applications of compressed natural gas (CNG) in gasoline engines. The goals of these projects were to provide a low-cost retrofit technology based on natural gas which would offer alternatives to the rising cost of oil. The developed vehicle conversion systems were technically feasible for conversion of gasoline engines. They were limited, however, to fleet vehicles because of a lack of adequate refueling and distribution systems.

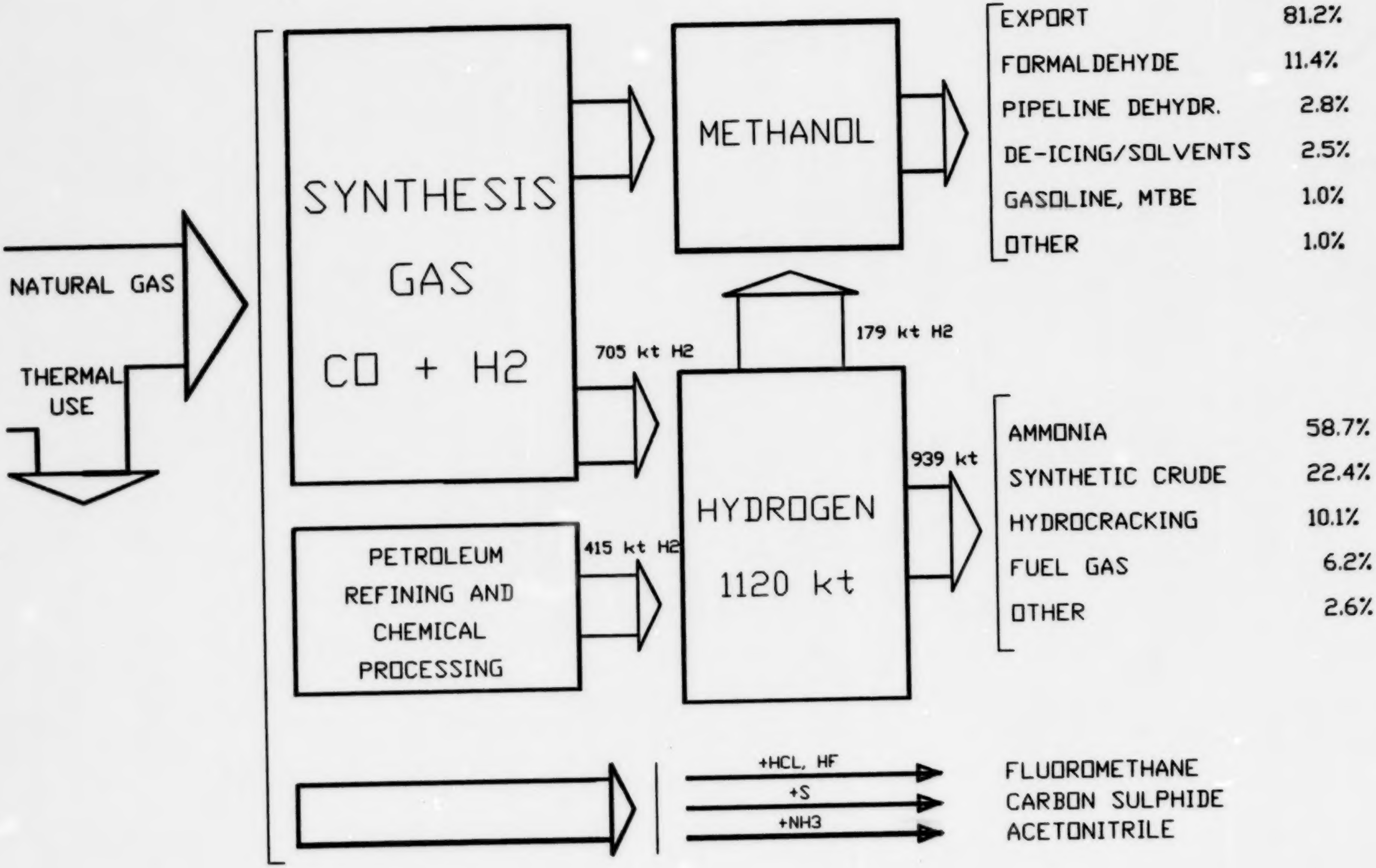

Figure 3. NATURAL GAS USE FOR FUEL COMPONENTS AND CHEMICALS

Several pilot projects were also run for conversion of diesel engines to CNG; however, since diesel engines require more extensive modification such as the addition of a spark ignition system, etc., less conversion took place for diesel replacement.

We expect that the recent increase in concern about air-pollution problems in urban centers will result in tougher diesel emission regulations, which can not be met by conventional diesel technologies. This will increase the use of NGV technology for buses and medium-sized fleet trucks. Environmental regulations on heavy diesel powered vehicles could be implemented without the inconvenience of strict imposed standards on private vehicles and, thus, they would likely receive public support. As an alternative solution, diesel emissions could also be reduced by installing emission control equipment or using alternative fuels such as methanol.

A number of technical areas need further improvement to demonstrate that NGV technology would operate reliably and economically with less air-polluting emissions. Examples are:

a) development of better conversion hardware (advanced spark ignition systems, etc.).

b) development of less costly refueling systems (gas storage, compressors, etc.).

c) development of dual-fuel, diesel engines for natural gas and diesel.

2.5.2. Methanol

Markets

Canadian methanol production capacity increased significantly during the 1980's, with 1987 capacity exceeding 1957 kilotonnes (Figure 4). About eighty percent of the capacity is dedicated to exports to Europe and the Pacific rim. As a result, Canadian methanol production for export is subject to frequent variations in the European and Asian market demand and has to compete with a low-cost methanol produced in the Middle-East and Trinidad. Canadian exports of methanol to the U.S. increased only recently to over 500 kilotonnes per year.

The domestic demand for methanol is only a small part of the total production (Figure 4). Major domestic methanol uses include the production of formaldehyde, dehydration of pipelines, and production of de-icing liquids and solvents. The percentage of methanol used as fuel increased from near zero in 1984 to 16.5 kilotonnes (5.4 percent of domestic methanol use) in 1987.

The largest future growth in methanol consumption is expected in methanol end-use as a transportation fuel substitute or fuel component. Several projects are in place today to research the direct use of methanol in dual-fuel cars or in running neat methanol in buses and trucks. These projects are expected to yield information on the technical feasibility of the direct application of methanol as a transport fuel by 1990.

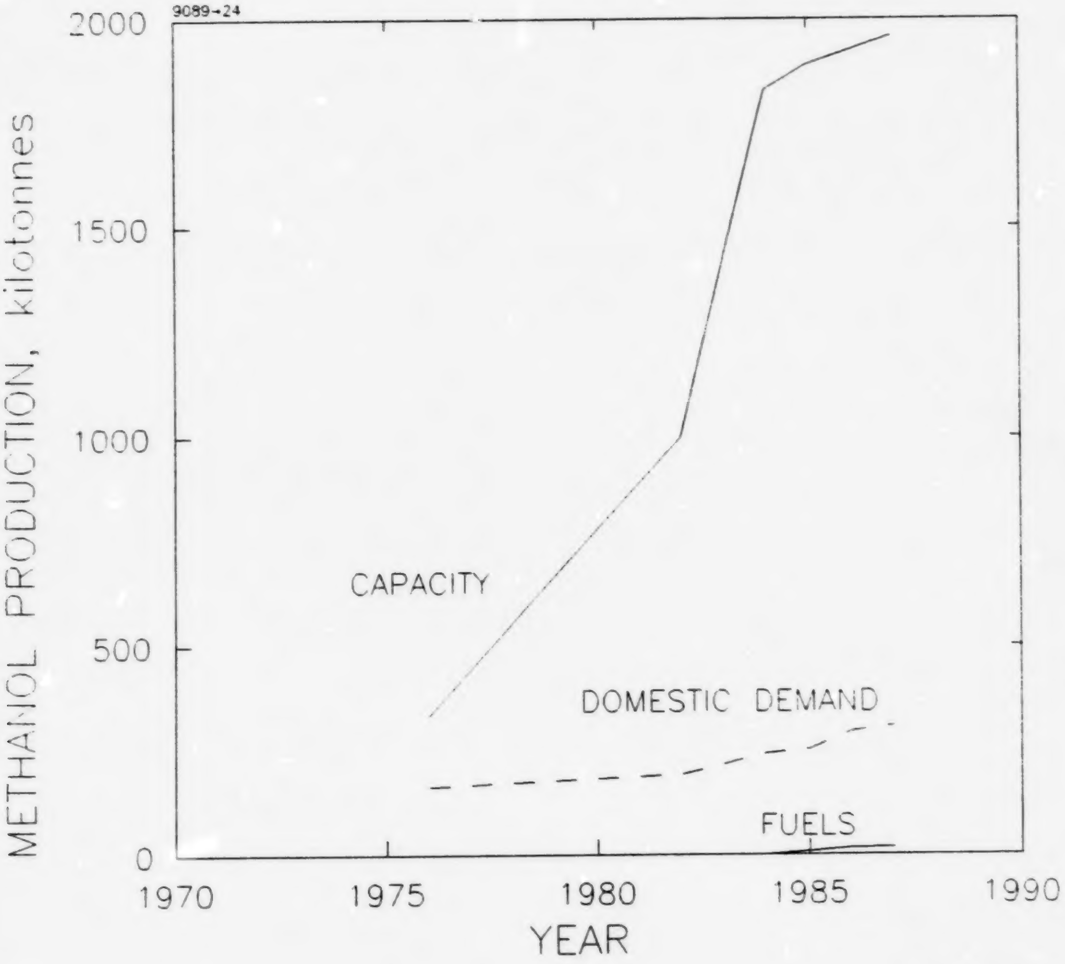

Figure 4. HISTORICAL DATA FOR CANADIAN METHANOL PRODUCTION AND DEMAND

The demand for methanol as a feedstock for MTBE in North America has steadily increased since the early 1980's. The planned phase-out of lead in gasoline (in December 1990 in Canada and 1992 in the U.S.) has already resulted in 10 percent of methanol end-use for MTBE in the U.S. Because demand for unleaded gasoline will increase, methanol end-use for production of MTBE may reach levels similar to methanol use in the production of formaldehyde (190 kt per year in Canada).

Methanol can be converted to gasoline or diesel-like transportation fuels. There is, however, only one plant, today, in New Zealand, which produces synthetic gasoline from natural gas, using the Mobil MTG methanol synthesis route. The New Zealand plant converts about 500 million gallons of methanol per year, at above 90 percent gasoline yield thermal efficiency.

Methanol Technology

Today, four major companies offer world-wide methanol synthesis technology. These are Imperial Chemical Industries (ICI), UK; Lurgi, West Germany; Mitsubishi, Japan; and Halor-Topsoe, Denmark. All of the processes use synthetic gas as a feedstock and copper/zinc oxide as a catalyst. On average, these processes achieve 81 percent carbon efficiency and 65 percent thermal efficiency based on crude methanol product. Their ultimate process thermal efficiencies are estimated at 80 percent of the input energy in synthesis gas.

Several improvements to the existing commercial technology are offered by the process developers or are close to being offered. These include production of synthesis gas with a $H_2/CO/CO_2$ ratio closer to a stoichiometric by including a secondary reactor with a bypass methane and oxygen to produce a carbon rich synthesis gas, or process configuration including catalytic partial oxidation of methane with steam and oxygen. The new processes also include an improved catalyst which is much more resistant to sulphur, hence a variety of feedstocks from natural gas to No. 2 fuel oil can be used.

Research and development work is being continued on new catalyst formulations and improved synthesis reactor design. New catalysts such as copper-thorium or copper-cerium exhibit higher activity and can produce higher alcohols which have better motor blending properties than methanol. In the area of synthesis reactor design, three-phase reactors which operate more efficiently and remove the methanol product from the reactant stream have been studied.

The new technological advances and process designs will make methanol synthesis more efficient and more feasible for small capacity plants. It is difficult to envisage, however, a technological break-through in methanol synthesis based on indirect methane conversion, because the technology is mature and has been well researched. A break-through in methanol synthesis could be envisaged for a direct methane to methanol conversion process (see section 2.5.4).

2.5.3. Hydrogen Production

Markets

Canadian hydrogen production capacity has significantly increased since 1983 because of an anticipated strong demand for ammonia and methanol. The actual demand for these chemicals remained, however, well below expectation with the 1987 demand reaching only 1120 kilotonnes of hydrogen or 62.9 percent of the total capacity of 1800 kilotonnes (Figure 5). The major sources of feedstock for hydrogen production are synthesis gas from natural gas (about 63 percent), hydrogen produced as a petroleum refinery by-product and hydrogen by-product from electrochemical processes (Figure 3).

The majority of the hydrogen end-uses is for ammonia production (about 50 percent), for methanol (15.9 percent) and for the upgrading of bitumen and heavy oil to synthetic crude (18.8 percent). Other hydrogen uses are for petroleum refining and polishing, as a fuel gas, in the production of chemicals in the food and metal industries (Figure 3).

The demand for hydrogen for the upgrading of bitumen and heavy oil has steadily increased from 5 PJ in 1976 to 25.2 PJ in 1987 (equivalent 1×10^9 cubic metres of natural gas or 1.5 percent of Canadian natural gas consumption). On average, bitumen upgrading used about 0.02 tonnes of hydrogen per cubic metre of synthetic crude, based on 1987 consumption data.

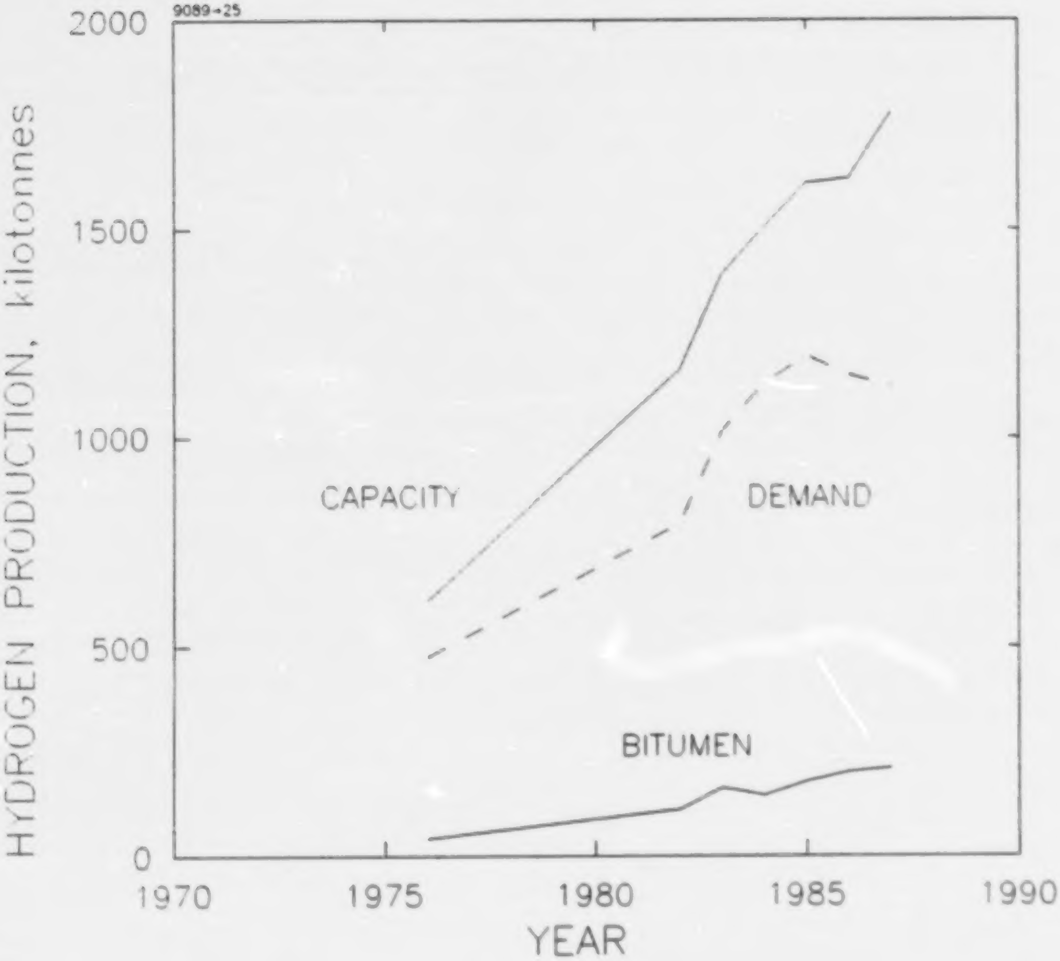

Figure 5. HISTORICAL DATA FOR CANADIAN HYDROGEN PRODUCTION AND DEMAND

The NEB (1988) projects, under a scenario of high economic growth and high oil prices ($30/bbl), an increase in synthetic crude production from bitumen from 10 million cubic metres in 1987 to 32 million cubic metres by the year 2005. If natural gas were to replace the bitumen production or were to provide hydrogen for upgrading, the additional natural gas consumption would be 23 billion and 1.5 billion cubic metres, respectively (Figure 6). Such a demand for natural gas can be potentially supplied by the existing natural gas reserves and production capacity, without huge expenditures on new infrastructure and production plants.

The NEB (1988) also projects an increase in light crude oil imports from 58 million cubic metres per year in 1982 to 95 million cubic metres per year in 2005, under a low world oil price scenario ($20/bbl). For a high oil price scenario, the NEB projects imports to decrease to 44 million cubic metres because of offshore oil production from the Atlantic region. Since direct use of natural gas (NGV) or the conversion of natural gas would not likely be competitive under the low-oil price scenario, the potential for natural gas replacement of oil imports would be limited to 44 million cubic metres per year of crude oil (Figure 6).

Hydrogen Technology

In Canada hydrogen is produced via the high temperature steam reforming (HTSR) of natural gas, partial oxidation of methane, salt and water hydrolysis, and catalytic cracking of

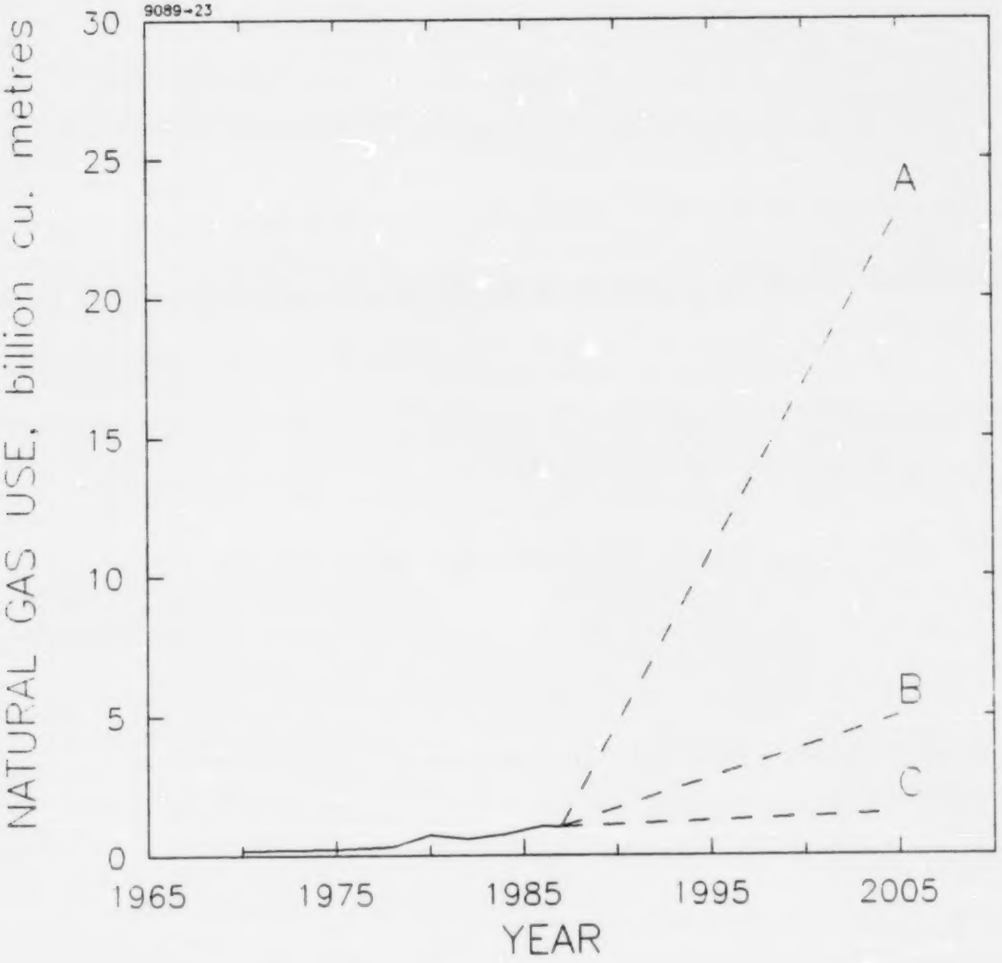

Figure 6. POTENTIAL DEMAND FOR NATURAL GAS TRANSPORTATION SUBSTITUTES OR FUEL COMPONENTS (YEAR 2005)
A - Replacement of Bitumen Production
B - Replacement of 10 Percent of Imports
C - Hydrogen Production for Bitumen Upgrading

hydrocarbons. Since the previous section discussed partial oxidation technology for methanol production, this section only briefly reviews HTSR technology.

The HTSR process is based on reaction of steam with hydrocarbons (methane or naphtha) over a nickel catalyst promoted with a combination of alkali and other metals. The reaction is endothermic, $CH_4 + H_2O = CO + 3H_2$, and the process heat is supplied in a reformer tube furnace by combustion of the feedstock.

The HTSR reformers typically operate at a steam to carbon ratio of 2.5 to 5.0, at temperatures 700°C to 870°C and pressure up to 35 atm. The HTSR system would include removal of various impurities such as sulphur compounds to prevent poisoning of the HTSR catalyst. On average, HTSR reformers achieve 78 percent thermal efficiency based on the gross heating value of the product (hydrogen).

Most of the recent advances in HTSR technology may be considered as improvements of the existing technology. The HTSR R&D has been aimed at a better use of feed and fuel, less costly fabrication and operation of equipment, and extension of the feed base to higher hydrocarbons. The most significant of recent improvements are a more efficient heat recovery reformer section, new combustion systems and materials of construction, and introduction of pressurized combustion reformer.

Today's designs of the HTSR reformers incorporate more heat recovery in the convection section and more air preheating to lower the amount of fired fuel required. New burners and control systems capable of handling variations in fuel composition are also installed in new plants. Other advances include application of ceramic insulation, which has a lower weight and can be prefabricated, and improved production techniques for reformer tube manufacturing, which allows higher reformer operating pressure and longer service life.

New developed catalysts for steam reforming are able to tolerate higher sulphur feedstocks and, thus, can process high boiling distillate fuel oils. The development objectives are to process feedstocks like No. 2 fuel oil, with 0.4 percent sulphur, with the efficiency and economy comparable with the reforming of natural gas.

An interesting HTSR system, using a pressurized combustion reformer, was developed by the United Technologies for production of hydrogen for large fuel cells. The reformer is much smaller as compared to conventional reformers, and can be shop fabricated. The reformer's design uses a pressurized combustor to increase the heat transfer and reduce the size of the furnace. The pressurized combustor/reformer has an overall feed and fuel requirement of less than 400 BTU per cubic foot of hydrogen, or above 80 percent gross thermal efficiency.

2.5.4. Direct Conversion of Natural Gas to Methanol and Higher Hydrocarbons

This section provides a brief review of the status of direct methane conversion technology including the process routes, efficiency, selectivity and relative performance versus indirect methanol synthesis routes. A detailed review of the direct conversion of methane process was presented elsewhere (Yarlagadda et al., 1987; Pitchai and Klier, 1986).

Direct methane conversion technologies to methanol and higher hydrocarbons can be divided into four types of chemical processes:

1. Direct partial oxidation (DPO) to methanol, methyl halides, etc. which involve reactions of methane with oxidants such as oxygen, nitrous oxides, and halides. Typical products of DPO are methanol, oxygenates, methyl halides and hydrocarbon.
2. Oxydative coupling (OC) to ethylane, which involves reactions of two methane molecules to ethane. The surplus of hydrogen is reacted with oxygen and removed as water.
3. Direct conversion of methane to acetylene and higher hydrocarbons, which involves thermal pyrolysis, electric arc and plasma, and partial oxidation. The products are acetylene and high hydrocarbons.
4. Other processes involving acetylation reactions with hydrocarbons, methane activation reactions with metals, metal oxides and complexes, etc.

A summary of each route including the status of the process and its relative advantages are given in Table 1.

The commercial feasibility of the direct methane conversion processes are primarily determined by the yield and selectivity of the methane reactions. The process conditions are relatively

TABLE 1. REVIEW OF DIRECT CONVERSION PROCESSES

PROCESS	CONDITIONS	REACTANTS/PRODUCTS	ADVANTAGES/DISADVANTAGES
DPOM	350-500^{0}C high pressure	O_2 / Methanol	high methanol selectivity favorable chemical equilibrium status: exploratory
DPOM	500-600^{0}C moderate pressure	N_2O / methanol, formaldehyde	high selectivity favorable chem. equil. N_2O more costly than methanol status: basic and exploratory
DPO	200^{0}C low pressure	Cl_2 / CH_3Cl	high conversion and selectivity corrosive & toxic product chlorine undesirable in gasoline status: basic and exploratory
DPO	<200^{0}C	superacids / C_2 hydrocarbons	low temperatures low conversion, corrosive catalyst status: basic and exploratory
OC	500-900^{0}C	MO_X / C_2H_4, C_2H_6	favorable chem. equil low conversion high paraffin content in products status: exploratory
METHANE TO ACETYLENE	1500-2500^{0}C low pressure	energy / C_2H_2	requires large amounts of energy, high temperatures status: commercial
ALKYLATION	<300^{0}C	C_2H_4,C_6H_6/C_3H_8,$C_6H_5CH_3$	reactants more valuable than products undesirable oligomenization self-alkylation status: basic
METHANE	?	M,MO_X / C_2-hydrocarbons	moderate reaction conditions status: basic research

DPOM = DIRECT PARTIAL OXIDATION TO METHANOL

OC = OXIDATIVE COUPLING

favorable (low temperatures and pressures) so that product yield, product selectivity and catalyst cost largely determine the process economics. Kuo (1987) studied direct partial oxidation of methane to methanol and oxidative coupling of methane to methanol versus indirect methanol production routes. The study suggests that in order to be competitive with current indirect processes (e.g., ICI process), the required range of selectivity and conversion for direct conversion processes will be:

1. For direct partial oxidation: > 80% selectivity
   > 7.5% conversion
2. For oxidative coupling: > 88% selectivity
   > 35% conversion

An example of the evaluated performance of a direct conversion process (DPOM) versus an improved methanol synthesis process is given in Table 2. It is apparent that at methane conversion of 7.5 percent per reactor pass and selectivities of 90 percent, direct partial oxidation exhibits a superior performance (i.e., higher thermal efficiency, lower heat transfer and required equipment duty).

Figure 7 depicts the selectivity and conversion of selected DPO and OC processes from literature. It is apparent that as the conversion of each route increases, the selectivity decreases. Also, only a few direct conversion routes are commercially viable as judged by Kuo's criteria for selectivity and conversion.

Table 2. CONVERSION OF NATURAL GAS TO METHANOL

	VIA STEAM REFORMING	DIRECT PARTIAL OXIDATION
FEED AND REACTOR		
NG to Reactor, %	78.3	100
$(H_2 - CO_2)/(CO + O_2)$	2.03	N/A
MeOH Selectivity, %	—	90
Single-Pass Conversion, %	—	7.5
Total C-Conversion, %	96.9	96.7
THERMAL EFFICIENCY (% NG LHV)	68	69
EQUIPMENT		
DUTIES (to NG LHV)		
Heat Trans.	171	83
Compression	21	21
Expansion	5	0

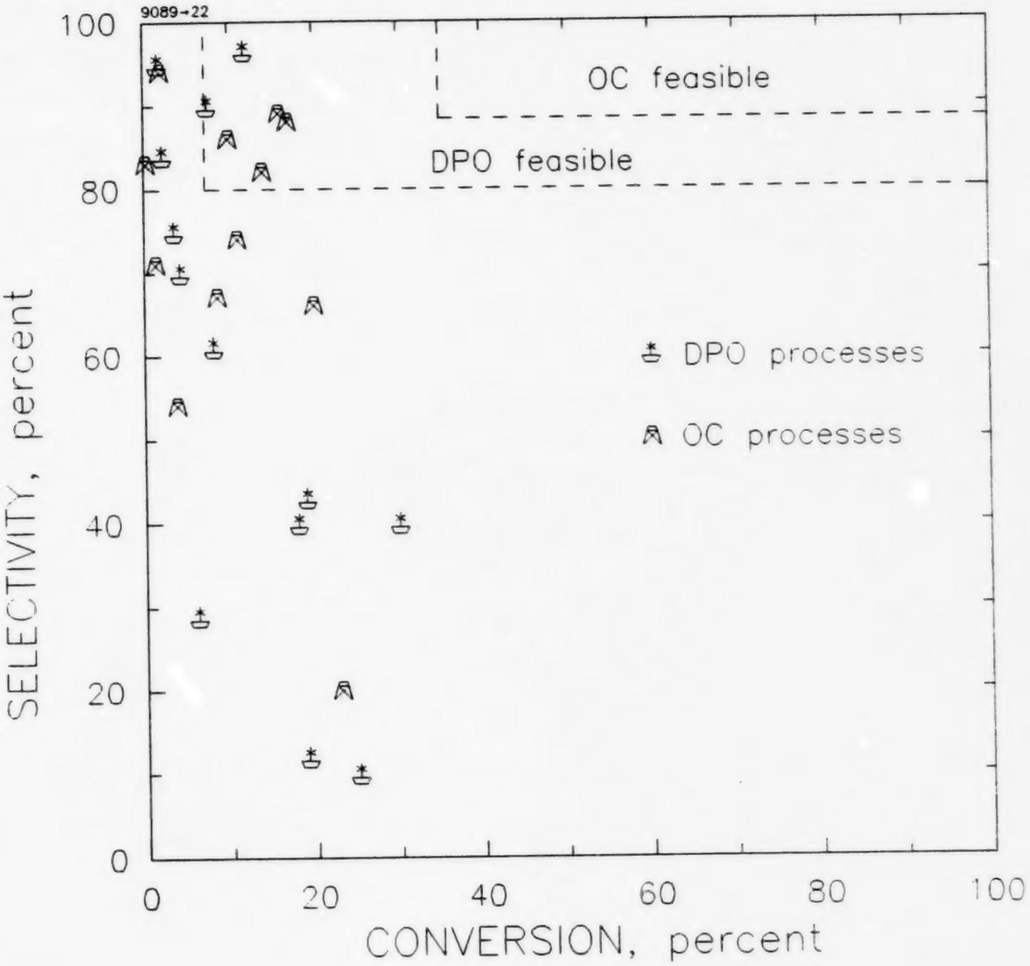

Figure 7. **RELATIONSHIP BETWEEN SELECTIVITY AND CONVERSION FOR DIRECT METHANE CONVERSION PROCESSES**

The continued high interest in direct conversion technologies stems from several potential process advantages that direct routes may offer:

a) thermodynamic calculations indicate that direct conversion routes can have higher ultimate thermal efficiencies.

b) equipment duties such as heat transfer, gas compression, etc., are more favorable for direct routes.

Direct methane conversion routes must, however, achieve sufficiently high conversions and selectivities in order to offer these advantages and to be economically viable. Further research on catalyst and process development should be directed toward maximizing the advantages and increasing the economic viability of direct conversion routes.

3.0. KEY FACTORS DETERMINING NATURAL GAS USE IN CANADA

The following sections will briefly address variables affecting the current natural gas usage in various end-use sectors of the Canadian economy. Next the discussion will focus on groups of variables which have been identified as key factors that should be considered when assessing future changes in natural gas usage within the Canadian economy.

3.1. Variables Affecting Natural Gas Usage

3.1.1. Residential

Energy use per household is a function of the age of the home (new homes are much more energy efficient), energy prices and household income. The more disposable income that is available, the higher the energy use and the less of an impact that higher energy prices or the cost of energy will have. Trends in energy efficiency for appliances and furnaces and amount of insulation used will continue to lower overall energy use per household as housing stock is replaced.

For the residential market, natural gas prices have historically been 50 percent lower than electricity and 25 percent lower than light fuel oil. Therefore, in areas where a natural gas distribution system is available, the market penetration of natural gas in the residential sector is very high. However, as the distance from the western Canadian gas producing areas increases, the potential for competition with electricity or light fuel oil increases. In Quebec, for example, electricity competes head-on with natural gas for the residential market.

Government "off-oil" programs have been very successful across Canada and there is not much remaining potential for new gas markets at the expense of oil. The only exception is in the Atlantic provinces where natural gas is not now available. Expansions of natural gas distribution systems to less densely populated rural areas have occurred in Alberta and Saskatchewan, but these projects have not been economically self-sustaining. They have required some form of subsidy either from government or from the other natural gas users on the system.

The key variables affecting natural gas usage by the residential sector will be the number of households, the relative energy prices of near substitution in those areas where natural gas competes with an alternate fuel, and the level of household or disposable income which in turn is related to the growth rate of the GDP. With respect to the latter factor, it is unlikely that an energy price change, either up or down, could occur with enough magnitude to significantly alter the natural gas usage pattern of the residential sector.

3.1.2. Commercial

For the Canadian commercial sector, natural gas prices have historically been 65 percent lower than electricity prices and 40 percent lower than light fuel oil. Currently, natural gas supplies 36 percent of the overall energy requirements of the commercial sector. Conservation efforts, more efficient lighting, heating and cooling systems, microprocessor based control systems, energy recovery systems, etc., make modern commercial buildings much more efficient than older building stock. Also, commercial users are more sensitive to energy prices than the residential users and are quicker to adapt new energy technologies and to switch between fuels if it is profitable to do so.

The key variables affecting natural gas usage by the commercial sector will be relative energy prices and the number of buildings. Economic activity or the growth rate in GDP will directly affect the rate at which new buildings are added or older buildings upgraded.

3.1.3. Industrial

Energy use in the industrial sector has been significantly affected not only by the conservation and efficiency efforts of the late 1970's and early 1980's but also by a shift from energy intensive "smoke-stack" industries to less energy intensive service and "high-tech" industries.

The largest user of natural gas in Canada is the industrial market, and currently natural gas supplies 39 percent of the overall energy requirements of the industrial sector.

Natural gas competes with fuel oil as a boiler fuel and as a source of direct process heat in most of the heavily industrialized areas of Canada - Ontario, Quebec and on both the east and west coasts. In some areas natural gas competes with coal as a boiler fuel but this represents only a very small part of the industrial sector's energy requirements. Natural gas competes with electricity in some provinces where large surpluses of hydro power exist and where utility policy allows head-to-head competition - i.e., Quebec.

Key variables affecting natural gas usage in the industrial sector will be relative energy prices, economic activity (GDP) and the role of investment in Canada's industrial sector.

3.1.4. Petrochemicals

Petrochemicals include the production of ammonia, methanol, olefins, aromatics and other related products.

Feedstocks for this industry come primarily from the natural gas fields in western Canada although, offshore oil is used as a feedstock for some production in eastern Canada. Markets for this industry are both domestic and international and, therefore, the health of the petrochemical industry in Canada generally follows world-market cycles of "boom-or-bust".

The competitive position of the petrochemical industry in Canada suffers from two basic problems; the cold Canadian climate which adversely affects the capital and operating costs of world scale plants built in this country and the high transportation costs to world markets for plants located close to the conventional gas producing areas in western Canada. Thus, if the Canadian petrochemical industry is to compete successfully in world markets, Canadian feedstock costs must be kept low enough to offset these disadvantages.

In a free trade environment with the U.S., Canadian producers will have to compete head-on with lower cost U.S. Gulf coast plants which utilize oil as a feedstock. Portions of the Canadian petrochemical industry, such as ammonia production, have successfully operated under tariff-free market conditions with the U.S. for years. However, other segments of the industry such as the manufacture of polyolefins, will have to adapt to the reduction in tariffs.

Currently the petrochemical sector utilizes 11 percent of the natural gas consumed in Canada on an annual basis.

Key variables affecting natural gas usage by the petrochemical sector will be the growth in domestic and world markets for petrochemical products (which, given Canada's open economy will be a function of the growth in GDP) and world oil prices versus natural gas prices in Canada.

3.1.5. Transportation

Energy use in the transportation sector is primarily related to the number of motor vehicles, the average vehicle fuel efficiency and the average distance driven per vehicle. The efficiency of vehicles has increased dramatically over the last decade and it is expected that this trend will continue. The number of vehicles which will be affected by the level of disposable income is in turn related to the growth rate in GDP. The level of disposable income will also affect the degree to which a significant increase in energy prices could have an impact on the average distance driven.

Currently, only 5.6 percent of this sector's energy requirements are supplied by natural gas. Although compressed natural gas (CNG) can offer reduced operating costs for automobiles and trucks, the main problem is the availability of CNG fuelling outlets. Because of the relatively high capital costs involved, most of the CNG fuelling outlets in Canada have been established with government assistance. Further, because of the conversion costs per vehicle, interest in CNG has been limited to commercial fleets operating in relatively confined geographic areas.

The federal government's plans to phase-out lead from gasoline by 1991 provides a new potential market for natural gas. The market exists for natural gas if it is used as the feedstock for methanol or methyl ter-butyl ether (MTBE) which, as octane boosters, are potential replacements for lead. However, natural gas conversions to methanol or MTBE are subject to the economic considerations of world-scale petrochemical manufacture.

3.1.6. Export Market

Natural gas has been exported to U.S. markets in significant quantities since the 1950's. During the 1970's, gas exports to the U.S. ranged between 25.0 billion and 29.1 billion cubic metres per year. However, with the implementation of the National Energy Program and export controls, natural gas exports to the U.S. dropped to between 20.2 billion and 22.6 billion cubic metres per year from 1980 to 1984. With changes in federal and provincial government policies since 1983, export regulations have been relaxed and gas exports to the U.S. have grown to 28.0 billion cubic metres in 1987 (NEB, 1988).

To put the magnitude of natural gas exports in perspective, during 1987 the total production of natural gas in Canada was 62.4 billion cubic metres of which 45 percent was exported to the United States (NEB, 1988).

The key variables affecting the export of gas to the U.S. market will be the relative energy prices of competing fuels in the U.S. (oil products, coal and U.S. natural gas production), political and regulatory activities on both sides of the border, and growth in the demand for energy in the U.S. market. Structural changes have taken place in the U.S. economy similar to those in Canada, and a large growth in U.S. imports of energy may not occur. However, with the advent of free trade for all sectors of the Canadian and U.S. economies, the effect of the rate of change in GDP on the demand for natural gas should be similar in both countries.

3.2. Key Factors

Task 2 of this project included the preparation of a complete list of the relevant variables or issues that affect the energy supply and demand situation in Canada. The following section addresses only those variables from the list which affect the demand for natural gas in Canada. These variables have been grouped under the following seven headings which have been identified as being key factors that should be considered when assessing future changes in natural gas usage within the Canadian economy:

1. availability and price of natural gas.
2. efficiency of natural gas usage in existing end-use applications.
3. fuel interchangeabilities.
4. government involvement in the economy.
5. environmental concerns.
6. general economic parameters.
7. structural changes.

3.2.1. Availability and Price of Natural Gas

Security of Supply

The comparison of natural gas reserves in Canada versus its closest fossil fuel alternates has been addressed in detail in Section 1.0.

In terms of its closest alternate, established gas reserves in Canada's conventional frontier regions are more than twice as large, on an oil equivalent basis, as crude oil reserves. In addition, there are significant additional gas resources in both Canada and the U.S. which can be brought into production given high enough market prices. When all factors are considered, including current costs for exploration and transportation versus reserves, resources and market demand, natural gas in Canada has and is perceived to have a reliable and secure source of supply.

Pricing Mechanisms

The commercial terms affecting the sale, transmission and distribution of natural gas are established today, to a very high degree, in a market-oriented environment. This means that rather than a single reference price for natural gas which has been set by regulation for the country as a whole, consumers and producers in the market place determine the terms and conditions for each sale.

With market forces setting prices for natural gas and oil, the relative economics of each individual fuel supply decision will determine the energy supply mix for the country. This is in contrast to the situation under the National Energy Program where an overall decision was made to encourage the Canadian economy to move "off-oil" and a series of variables - market prices, taxation policies, legislated vehicle efficiencies, etc. were manipulated by the government in an attempt to achieve the desired change in the energy supply mix.

With market-oriented pricing mechanisms, responses to changes in the relative pricing of alternative energy forms will be more rapid due to the absence of "regulatory lag", and the responses will not likely be different than under a centrally regulated pricing system. In addition, new marketing mechanisms have emerged with the deregulation of natural gas in Canada which allow more flexibility in the supply - demand balance, i.e., shorter term supply contracts, direct purchase arrangements, etc.

The price of oil in Canada is totally deregulated and is determined by international supply and demand factors which are beyond Canada's control. The price of natural gas in Canada, given the movement towards complete deregulation, will be set by the demand for gas in Canada and for export to the U.S., and by the incremental costs of supplying gas to the marketplace from Canadian reserves.

Since deregulation in November, 1986, natural gas prices have been relatively insensitive to supply costs, as well as to changes in world oil prices, because of the over-supply of natural gas in North America. As noted in earlier sections, natural gas enjoys a competitive pricing edge in most markets over oil and some upward movement in natural gas prices could occur without affecting the competitive balance. Incremental supplies from Canadian reserves will become more costly, and as the supply and demand balance tightens, prices will rise and will begin to reflect the cost of the addition of new reserves.

Availability

The conventional natural gas markets in most parts of Canada and the U.S. can be described as relatively mature. Pipeline infrastructures in Canada and the U.S. have been in place for some time and in good part have been fully depreciated. The transportation costs from established production areas to conventional market areas are therefore relatively low.

A substantial expansion of domestic natural gas markets in Canada would require major infrastructure developments which would be costly and which without subsidization of some form will not take place. Market-oriented pricing does not facilitate cross-subsidization, and given current energy prices there is little necessity for government activity in this area. As noted earlier, the availability of supply and distribution systems for CNG as an alternate fuel falls into this category.

Exports of natural gas to the U.S. are on the increase as a result of relaxed Canadian export controls, the perceived security of supply of natural gas, the removal of regulatory constraints by U.S. regulators and current market pricing which makes Canadian natural gas a very attractive alternate. Exports of gas to certain parts of the U.S. are constrained by pipeline capacity, however, several sizeable projects have recently been approved by the NEB to increase transmission capabilities to the northeastern and west coast U.S. markets.

U.S. reserves of oil and gas have been more fully exploited than those in Canada. The U.S. will become more reliant on imports of oil and gas as the production of these commodities declines in the U.S. and as the incremental costs of production increase more rapidly there than in Canada. However, the United States now has a post-industrial type of economy and the continuing benefits of energy efficient technologies and conservation are being realized in all sectors of the U.S. economy. Therefore, large growth in U.S. imports of natural gas from Canada, to the extent currently envisioned by some gas producers, may not occur.

3.2.2. Efficiencies in Existing End-Use Applications

The present uses for natural gas and current technology have been addressed in earlier sections. In summary, the implementation of currently available technology will continue to improve the efficiency of natural gas usage and this will serve as a "brake" on the growth rate in gas usage in conventional residential, commercial and industrial applications. However, given the economic advantage that natural gas has in the Canadian marketplace over its near alternatives, the growth rate for the use of natural gas for conventional markets will not be negative unless the Canadian economy experiences a recession similar to the one that occurred in 1981.

With respect to the petrochemical industry, Canadian productivity and the Canadian technological base should keep this industry competitive with the U.S. in terms of efficiency. The comparative feedstock prices of world oil versus Canadian natural gas will be a much greater variable.

The opportunities for natural gas in terms of new end-use applications was addressed in Section 2.

3.2.3. Fuel Interchangeabilities

Most of the natural gas that is consumed in Canada is used in combustion applications. The burner tip price of natural gas versus the price of its near substitutes will, for the most part, determine whether an initial equipment installation will be natural gas fuel oil, electrical or coal fired.

The large majority of heating systems in Canada for residential and commercial use are designed for only one fuel source and once the initial equipment has been installed it normally will not be replaced until its useful mechanical life is over. As an example, even after fuel oil prices had increased significantly in Canada by the late 1970's, the federal government found it necessary to provide grants to encourage residential customers to either upgrade their heating equipment or to switch to some fuel other than oil. Because natural gas is the fuel of choice for most residential and commercial applications, and because of the tendency for these customers to retain equipment until its useful life is over, the price elasticity for natural gas is relatively low.

Fuel interchangeability in the industrial market is more sensitive to the relative burner tip price of near alternatives. It is common for dual firing capabilities to exist in Canadian industry, either specifically for the ability to switch between alternative fuels depending on price (i.e., natural gas versus heavy fuel oil in Ontario or Quebec) or because of security of supply considerations (i.e., a light fuel oil back-up system to a natural gas fired boiler). As fuel diversification capabilities increase, interfuel competition of the burner tip increases. A trend towards greater fuel diversification capabilities can be expected for Canadian industry.

It should be noted that the U.S. industrial sector has much greater interfuel competition than is the case in Canada and coal plays a greater role in the U.S. as an industrial fuel. Hence, price elasticity in the U.S. for Canadian natural gas exports can be expected to be greater than for natural gas usage by Canadian industry.

With respect to the Canadian market, electricity is generally the most expensive energy source, followed by oil, then natural gas and finally coal. Although coal is quite often the lowest cost alternative on an energy content basis, the significant capital and operating costs associated with its use, the material handling, storage and operating problems, in addition to the environmental difficulties associated with the use of coal, make it a seldom used option other than in very large volume specialized applications such as electrical power generation.

One area where coal and natural gas will compete directly in future is for the generation of steam, or as a source of hydrogen for bitumen recovery, in in-situ heavy oil recovery, and for heavy oil upgrading. Current technology and economics favor natural gas over coal for these applications for many of the same reasons as outlined in the previous paragraph. However, the massive scale of bitumen and in-situ heavy oil projects and the significant quantities of hydrogen required for the upgrading of heavy oil, mean that economies of scale and future energy price differentials could make coal the preferred commodity.

3.2.4. Government Involvement in the Economy

The degree of government involvement in the Canadian economy and in the energy industry in particular is an important factor to be considered.

From the 1950's to the early 1980's, government involvement in Canadian oil and gas sectors went from essentially a "hands-off free market" approach to one of heavy regulation with increased public ownership and direct government intervention in the marketplace. Since 1983, the government approach has reversed and the movement has been towards deregulation, privatization and allowing market forces to prevail.

Government involvement in the energy marketplace has had both positive and negative effects. For the oil and gas industry in western Canada, policies such as the National Oil Policy of 1961 guaranteed western producers the Canadian market west of the Ottawa Valley and encouraged exports. In contrast the National Energy Program, which was unilaterally introduced by the federal government in 1980, had a definite negative effect on the oil and gas industry particularly because of pricing and export volume controls.

Government policies have been used in the marketplace to encourage conservation and efficiency improvements and to switch between fuels. However, government regulation and subsidies do distort energy prices to the end-user and the result may well be inappropriate or wrong signals to the marketplace.

The clear direction for regulation and government intervention in the North American marketplace today is for less government involvement. This helps to eliminate "regulatory lag" and possible mixed pricing signals for consumers which would be plus factors given volatile international energy markets and Canada's free trade agreement with the United States. However, private industry and the marketplace do not always function in the best interests of society in general. Given Canada's open-market type of economy, world energy markets will not be particularly sensitive to any undue hardships that may be created within specific regions of Canada, let alone the special interests of Canada as a nation. It should be a fairly safe assumption that as long as the supply/demand balances for the world's energy requirements stay relatively in line, the political will for government intervention will continue to wane. However, if a significant disruption in the supply/demand balance occurs, regulation and government intervention in the marketplace will once again be the order of the day.

The degree of government involvement in the economic aspects of the energy industry (i.e., energy and pricing aspects) will affect Canada's energy supply mix, the prices to be paid for energy by end-users, and the ease or difficulties with which transitions can be made to accommodate sudden and severe changes in international energy markets.

Government involvement will continue in any event, in areas such as research and development (i.e., to encourage the development of alternate transportation fuels, new heavy oil upgrading techniques, the conversion of coal to oil and gas products), longer range strategic planning for areas of the country where an alternate to oil is not readily available, and in the social aspects of the energy industry (i.e., environmental and safety considerations). In addition, government will continue to play a role in the facilitation of mega-projects which are beyond the normal risk-taking capabilities of private industry.

3.2.5. Environmental Concerns

Environmental issues that affect energy consumption in Canada are global in nature, i.e., acid rain, CO_2 build-up in the atmosphere and the attendant "greenhouse" effect, ozone layer depletion and pollution of the oceans.

From an environmental perspective, the cleanest of the conventional hydrocarbon fuels is natural gas, but even natural gas releases CO_2 when it is burned. If the greenhouse effect were to become a global crisis that required severe curtailment of fossil fuel combustion, natural gas would still be the preferred hydrocarbon fuel because of its clean burning characteristics relative to oil and coal. However, major structural changes would be required in the Canadian economy to effect significant enough gains in energy-use efficiency and conservation to lower CO_2 emissions. These changes would almost certainly include decreased natural gas usage. Alternates to hydrocarbon fuels are available (i.e., hydrogen fuels and electrotechnologies) but increased efficiencies and conservation are the most immediately available options.

There is also a growing recognition of the need to work towards a global economy based on "sustainable development" and of the impact that this has on the quantity and types of energy demands (i.e., the Brundtland Report, the World Conference on the Changing Atmosphere, and the federal government's Energy Options Report). Directionally, the suggested impact is lowered levels of energy demand, less hydrocarbon usage and more electrotechnologies in a more environmentally conscious economy.

As noted in an earlier section, the elimination of lead from gasoline provides an opportunity for the increased use of natural gas in liquid fuels in the form of methanol and MTBE as octane enhancers. In addition, where ambient pollution conditions necessitate reduced NOx, CO and hydrocarbon emissions, (i.e., Los Angeles, Denver and New York City), the use of alcohol/gasoline blends or CNG can be effectively utilized.

3.2.6. Economic Parameters

Canada has a relatively open economy - interest rates, inflation, balance of payments, value of the Canadian dollar, etc., are for the most part established not by Canadian policy but by international conditions. Thus, changes in economic activity in Canada (i.e., GDP) and its effects on energy consumption in this country will be linked to the general productivity of the Canadian labor force and the general well-being of the world's major economies. Given a competitive performance by the Canadian economy, generally healthy world economic conditions should translate into increased domestic and export demands for Canadian natural gas. However, problems in the world's major economies will also be directly transferrable back to the Canadian natural gas marketplace. For example, if massive defaults on third world debts cause increased interest rates around the world, the effects in Canada should be higher wellhead prices for natural gas due to the increased costs of investment capital and delays in the replacement of energy inefficient equipment.

The performance of the Canadian economy in terms of productivity will be increasingly important in the global marketplace. The effects of an aging population, changes in the composition of the labor force and changes in the types of industries in this country are all variables that will help determine Canada's productivity. In addition, international trade conditions and third world problems will increasingly affect Canada's open economy. However, as a single economic parameter, for the purposes of this study, the rate of change in Canada's GDP should adequately reflect both world market conditions and the relative performance of the Canadian economy.

3.2.7. Structural Changes

As noted in earlier sections, the oil price shocks of 1973 and 1979 have caused significant structural changes in the Canadian economy.

Adjustments in Canada and other OECD countries to the oil price shocks have resulted in the more efficient uses of energy per unit of economic output. The effect of these structural changes demonstrates that economic growth is not necessarily dependent on an equivalent growth in energy consumption.

The oil price shocks of the 1970's also demonstrated that there is a significant time-lag between the occurrence of a dislocation to the economy and the effects of any actions taken as a result of the dislocation. For example, even 10 years after the last oil price shock there continues to be significant increases in efficiencies in all forms of energy use. In fact, these effects are now taking place against a backdrop of oil prices that are much lower than those that caused the second shock back in 1979.

Part of the reason for the time-lag is that conservation efforts take time. Time for individuals and businesses to realize the economic implications of the shock imposed on the system, time for alternate courses of action to be developed either individually or at government levels, time to implement new measures, and time for the effects of the conservation efforts to be realized through the system. These time-lags are relatively short-term and they are related only to currently available technologies.

In instances where new technologies are required, the time lag is much greater. Energy technology development, that is applied research through to proven options, may take a couple of decades. The deployment of the proven new technology options may take an even longer time because of the life cycles of existing equipment. For example, residential furnaces have a lifetime in the order of 10 to 15 years, oil refineries and thermal generating plants have lifetimes in the order of 25 to 30 years and buildings and hydroelectric generating plants have life-times in the order of 50 years.

Even for the utilization of proven oil and gas reserves from frontier areas, for a given project to proceed, lead times in the order of 8 to 10 years are required for marketing and transportation arrangements, regulatory approvals, financing and the construction of the facilities.

Shocks, or dislocations to the economic system in the next two decades could take several forms. The magnitude and the "personal" impact of the dislocation will affect the speed of society's response and the amount of political will and resources that can be dedicated to react to the situation. However, based on the world's experience with the recent oil price shocks, the time-lag between the occurrence of a dislocation and the effects of any actions taken is most suitably measured in decades.

4.0. SUMMARY AND CONCLUSIONS

4.1. Canadian Energy Resources

Energy requirements in Canada today are being supplied from a multiplicity of sources. The majority of Canada's energy requirements are met from petroleum products (40 percent), followed by natural gas (25 percent), and electricity and coal (both at approximately 15 percent) (see "Major Constraints Associated with Markets", Figure 5).

Canadian reserves of marketable natural gas have doubled during the last twenty years whereas established conventional Canadian crude oil reserves have decreased by one-third. During the same time frame, the reserves to production ratio for conventional crude oil in Canada has decreased by over 50 percent versus only a 15 percent decrease for natural gas.

Crude oil's market share of Canadian energy requirements has decreased from 55 percent in 1965 to 40 percent in 1985. In addition, over these two decades, the use of oil in Canada became increasingly dedicated to transportation purposes because it is the major market area in which economic substitutes for oil based products are not readily available (see "Major Constraints Associated with Markets").

The market share of Canadian energy requirements for natural gas increased from 18 percent to 25 percent during the same period. The growth in natural gas use was primarily at the expense of oil due to the world oil price shocks of 1973 and 1979 and the federal government's "off-oil" programs. In addition, natural gas became an important raw material for petrochemical production with 60 percent of the petrochemical feedstock demand in Canada being met by natural gas or natural gas liquids by 1986.

Canada also has very large bitumen and coal resources and the utilization of these resources has increased significantly during the last twenty years. However, these resources are costly to develop and the economics of converting these resources into other useable energy forms along with the present low world oil prices are significant constraints to their increased utilization.

4.2. Conventional Use for Natural Gas

In 1987 about 89 percent of Canadian natural gas consumption was for direct thermal use in the residential, commercial and industrial sectors. The remaining 11 percent was used for the production of chemicals and fuel components. The largest thermal users are in the industrial sector, followed by the residential and agricultural sector and then the commercial sector. The largest petrochemical use is for ammonia and methanol production followed by hydrogen generation for the production of synthetic crude and refinery hydrocracking.

The key issues for the thermal use of gas over the last twenty years have been increased efficiencies and government "off-oil" programs. Increased efficiencies resulted from the significant rise in energy prices during the 1970's. The increased efficiencies were accomplished through the utilization of new equipment and technologies, better building designs and better thermal recoveries (i.e., better utilization of the available energy). Government programs during the last decade not only encouraged the more efficient use of all energy forms but they also encouraged a shift away from imported petroleum products to Canada's much more abundant natural gas and electrical resources.

The awareness of energy issues has increased significantly for all users in Canada particularly during the last decade. As a result of this awareness and the momentum created by the energy price shocks of the 1970's, the trend towards the more efficient utilization of energy continues in Canada today. This trend continues despite an over-supply of oil and natural gas and low prices for these commodities in the Canadian marketplace during the last two years.

In Canada, natural gas competes with petroleum products for thermal purposes only in industrial boiler applications, and in the more remote areas of the country where natural gas distribution systems have not yet been extended because of economic limitations. Natural gas competes with electricity for thermal purposes in industrial, commercial and residential applications across the country but more particularly in eastern Canada (i.e., as the distance from western Canadian gas reserves increases, the competition from electricity increases). Natural gas competes only to a very limited extent with coal for thermal purposes in industrial boiler applications.

The use of natural gas and petroleum products by utilities for electrical generation has moved down and up in tandem with the rise and fall of energy prices during the last twenty years. However, the use of natural gas for electrical generation has at best only been marginal and by 1987 only 3 percent of Canadian gas consumption was being used for power production. (NEB, 1988). This trend appears now to be changing because of the significant environmental issues affecting new coal fired plants, less costly installations and shorter planning horizons with natural gas fired generators, and an increased use of natural gas for cogeneration and combined-cycle plants.

In the area of utilization of natural gas for transportation uses, natural gas is limited to pipeline compressors and some NGV uses for fleets in urban areas. In addition, hydrogen that has been generated from natural gas for the production of synthetic crude or transportation fuels is approximately 3.4 percent of the current natural gas consumption in Canada.

Canada has also established a significant export market for natural gas to the United States and with the advent of the free trade agreement between Canada and the United States, the trend will be for this market to be more stable and to increase in size. The size of the export market is already significant. By 1987, 45 percent of the total production of natural gas in Canada was being exported to the United States. (NEB, 1988).

4.3. Natural Gas Conversion Technologies

Opportunities for the conversion of natural gas to liquid fuels or chemicals for transportation fuels are developing because of environmental concerns with diesel fuels, the removal of lead from gasoline which will require new octane enhancers to replace the lead additives, and an increasing reliance by the Canadian economy on imported crude oil and petroleum products which may be undesirable from the government's perspective for strategic reasons.

Current technology for the indirect conversion of natural gas to methanol, hydrogen or potentially other fuel substitutes has a limitation in terms of overall efficiency - at best the ultimate efficiency of indirect conversion is 80 percent gasoline yield thermal efficiency.

New technological advances and process designs will make methanol synthesis more efficient and more feasible for small capacity plants. However, indirect methane conversion technology to liquid fuels has been well researched and a significant technological breakthrough is unlikely in this area.

For the conversion of natural gas to liquid fuels and chemicals, the direct methane conversion route holds more promise. Direct conversion routes offer a higher ultimate potential efficiency. As well, capital costs for a direct conversion plant would be lower than the indirect conversion route because fewer process steps are involved and lower equipment duties from a thermodynamic perspective are required.

New chemical processes for direct methane conversion are being studied, but the work is still in the research stage.

4.4. Variables and Key Factors Affecting Natural Gas Usage

There are a large number of variables that affect natural gas usage by the various sectors of the Canadian economy. These variables can be described in broad terms as being technological, environmental, economic, regulatory or of a government policy nature.

The variables which define the Canadian situation can be grouped under seven headings. These headings have been identified as being key factors that should be considered when assessing future changes in natural gas usage within the Canadian economy. The seven key factors are as follows:

- **Availability and Price of Natural Gas** In terms of its closest alternate, established gas reserves in Canada's conventional frontier regions are more than twice as large on an oil equivalent basis as crude oil reserves. The supply and sale of natural gas in Canada has been making the transition during the last two years from being controlled by provincial and federal government regulations to being a deregulated open market commodity. As such, the commercial terms affecting the sale, transmission and distribution of natural gas are established today, to a very high degree, in a market-oriented environment. The price of natural gas in Canada will be set by the demand for gas in Canada and for export to the United States, and by the incremental costs of supplying gas to the marketplace from Canadian reserves.

The prices of oil and natural gas, in the absence of government regulation, have for the most part been decoupled in the marketplace.

- **Efficiencies in Existing End-Use Applications** The implementation of currently available technology will continue to improve the efficiency of natural gas usage and this will serve as a "brake" on the growth rate in gas usage in conventional residential, commercial and industrial applications. Also, growth within the existing conventional market areas will be very limited because the market penetration by natural gas is already very high.

- **Fuel Interchangeabilities** Canada enjoys a diversified energy supply and in most parts of the country, several alternative sources of energy are available for any given application. In general, electricity is the most expensive energy source, followed by oil and petroleum products, then natural gas and finally coal.

  Because natural gas is significantly lower in price than its near substitutes in most parts of the country, and because residential and commercial consumers do not normally change over equipment until its useful mechanical life is over, in the residential and commercial markets, the price elasticity for natural gas is relatively low.

  Fuel interchangeability in the industrial market is more sensitive to the relative burner tip price of near alternatives. As fuel diversification capabilities increase and the price of natural gas moves up relative to petroleum products, interfuel competition at the burner tip in this market area will increase.

  Where coal and natural gas may compete more directly in the future is for the generation of steam, or as a source of hydrogen for bitumen recovery, in in-situ heavy oil recovery, and for heavy oil upgrading.

- **Government Involvement in the Economy** Government policies have been used in the marketplace to encourage conservation and efficiency improvements and to switch between fuels. However, the clear direction for regulation and government intervention in the North American marketplace today is for less government involvement.

  The degree of government involvement in the economic aspects of the energy industry will affect Canada's energy supply mix, the prices to be paid for energy by end-users, and the ease or difficulties with which transitions can be made to accommodate sudden and severe changes in international energy markets.

Government involvement will continue in any event, in areas such as research and development and in the environmental and safety aspects of the energy industry. In addition, governments will continue to play a role in the facilitation of mega-projects which are beyond the normal risk-taking capabilities of private industry.

- **Environmental Concerns** Environmental issues that affect energy consumption in Canada are global in nature - i.e., acid rain, CO_2 build-up in the atmosphere and the attendant "greenhouse" effect, ozone layer depletion and pollution of the oceans.

  From an environmental perspective, the cleanest of the conventional hydrocarbon fuels is natural gas, but even natural gas releases CO_2 when it is burned. Alternatives to hydrocarbon fuels are available, but increased efficiencies and conservation are the most immediately available options.

  The elimination of lead from gasoline and increasing environmental problems with diesel fuel provides an opportunity for the increased use of natural gas in liquid fuels. In addition, where atmospheric conditions necessitate reduced NO_x, CO_2 and hydrocarbon emissions, alcohol/gasoline blends or NGV can be effectively utilized.

- **Economic Parameters** Canada has a relatively open economy and changes in economic activity in Canada and its effect on energy consumption will for the most part be established not by Canadian policy but rather by international conditions. Changes in energy consumption by the various sectors of the Canadian economy are primarily driven by changes in the country's GDP.

  In terms of a single economic parameter, the rate of change in Canada's GDP will reflect both world market conditions and the relative performance of the Canadian economy.

- **Structural Changes** The oil price shocks of the 1970's resulted in more efficient use of energy per unit of economic output thus demonstrating that economic growth is not necessarily dependent on an equivalent growth in energy consumption. The oil price shocks also demonstrated that there is a significant time-lag between the occurrence of a dislocation to the economy and the effects of any actions taken as a result of the dislocation. Shocks, or dislocations to the economic system in the next two decades could take several forms. The magnitude and the "personal" impact of a dislocation will affect the speed of society's response and the amount of political will and resources that can be dedicated to react to the situation.

4.5. Future Natural Gas Usage

Table 3 presents a summary of the 1987 demand for natural gas and the projected demand for natural gas in the year 2005, based on the NEB's 1988 Report. The NEB projections do not assume any shocks or dislocations to the current patterns of energy supply and demand or any significant technological breakthroughs. The NEB's projections are based on an average 2.2 percent annual economic growth rate for the Canadian economy.

There are a number of events that could create dislocations for the Canadian economy. The nature of the dislocation and the ability of the Canadian economy to adapt are the keys to future natural gas uses. Table 4 outlines a number of events that could create dislocations that would result in demands for natural gas differing significantly from the projections shown in Table 3.

In summary, increasing environmental pressures, energy shortages brought on by significant increases in the world demand for oil, sudden increases in real oil prices, increased world economic growth particularly associated with the rapid development of third world countries such as China and India, and technological breakthroughs on the utilization or conversion of natural gas

Table 3. CANADIAN TOTAL AND NATURAL GAS ENERGY DEMAND

	1987		2005[1]		
MARKET	TOTAL	NATURAL GAS	TOTAL	NATURAL GAS	INCREASE FOR N.G.
RESIDENTIAL	1239	475	1570	630	155
COMMERCIAL	956	342	1050	375	33
INDUSTRIAL					
Manufacturing	1734	722	---	1350	249
Mining	231	58	---		320[3]
Other	---	1	---		---
TRANSPORT	1709	96	---	130	34
ELECTRICITY	1840	55	---	140[2]	85
FUEL COMPONENTS AND HYDROGEN	---	50	---	110[2]	60
EXPORT	---	1059	---	1470	411
	N/A	2858	N/A	4205	1347

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[1] NEB (1988) forecast - low oil price

[2] Lobbe's estimate

[3] assumes natural gas use for bitumen recovery

Table 4. EVENTS THAT COULD CREATE DISLOCATIONS IN THE ENERGY SUPPLY/DEMAND PATTERN

EVENT	DESCRIPTION
1. Energy Glut	a) Continuing growth in supply of oil or oil substitutes. - "Orimulsion" from Venezuela - coal/water or bitumen/water fuels from Canada - horizontal drilling in Canada's heavy oil deposits - much larger reserves than expected from Alaskan Slope, North Sea, Saudi Arabia - technology breakthrough in tertiary oil production
	b) "Abionic" theory of natural gas origin proves true and deep drilling techniques bring on huge reserves of natural gas.
	c) Breakthrough in technologies to make alternate transportation fuels. - natural gas to liquid fuels - electronic automobiles - hydrogen fuels
	d) Era of electronics, computerization, high-tech & service industries. - less transportation required for movement of people and goods - working, banking, shopping, etc. done at home
2. Energy Shortage	a) War shuts off production and shipments of oil from strategic areas in world.
	b) Low oil and gas prices stimulate high world-wide economic growth coupled with less efficient use of energy. Low oil and gas prices also do not stimulate exploration and production to replace declining reserves.
	c) Normal economic growth causes tightening of world oil supplies and demand. OPEC regains dominant market position and increases prices through curtailment of production.

Table 4. EVENTS THAT COULD CREATE DISLOCATIONS IN THE ENERGY SUPPLY/DEMAND PATTERN (cont'd)

EVENT	DESCRIPTION
	d) Breakdown of eastern block political systems cause chaos and disruption in production from those areas.
3. Economic Threats	a) World-wide recession brought on by a financial collapse due to 3rd World debt problems and a wave of economic nationalism and protectionism.
	b) Breakdown of the world's relatively liberal trading system into fortress like trading blocks; i.e.: i) European Community ii) Canada, U.S., Mexico, Latin America iii) Japan and Asian countries iv) Eastern block nations
4. Economic Opportunities	a) Super companies (alliances and joint ventures on a global basis) operating in free trade super economies. Erosion of all kinds of barriers to trade and commerce. Costs drop and investment opportunities increase.
	b) Rapid industrialization of 3rd World countries. Countries like China and India become economic superpowers and greatly increase world demand for goods & services especially energy.
5. Environmental	a) Increasing levels of CO_2 in world's atmosphere requires global action to decrease use of fossil fuels, burning of world's forests etc.
	b) High public awareness of environmental issues and significant political pressures world-wide to move towards greater efficiencies and conservation efforts ("sustainable growth" of the Brundtland Report).

Table 4. EVENTS THAT COULD CREATE DISLOCATIONS IN THE ENERGY SUPPLY/DEMAND PATTERN (cont'd)

EVENT	DESCRIPTION
6. Other	a) Declining world birth rates (birth control) or an epidemic of a disease like AIDS slows the growth rate of or causes a decline in the world's population. Aging population slows productivity improvements and GNP's around the world.
	b) Medical breakthroughs or increasing birth rates swell world populations especially in 3rd World countries.

would all work towards increasing the competitiveness of natural gas and hence would increase the demand for this fuel.

Events such as a persistent energy glut perpetuated by the addition of large new oil reserves or the availability of new, economically priced oil substitutes, the development of practical fusion technologies, significant gains in the efficient use of all forms of energy, economic slowdowns associated with a world-wide recession, or a breakdown of the world's relatively liberal trading system would all impact negatively on the demand for natural gas.

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